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NATIONAL CROP LOSS ASSESSMENT NETWORK (NCLAN) 1985 ANNUAL REPORT

Prepared by the

Research Management Committee:

Walter W. Heck, Chairman
O. C. Taylor, Associate Chairman
Richard M. Adams
Lance W. Kress
David T. Tingey
Leonard H. Weinstein

Senior Scientists:

R. G. Admundson
A. S. Heagle
P. M. Irving
D. A. King
R. J. Kohut
J. A. Laurence
A. S. Lefohn
V. M. Lesser
J. E. Miller
J. R. Miller
G. E. Neely
P. J. Temple

and

Statistical Consultant:

John O. Rawlings

Project Officer:

David T. Tingey
Environmental Research Laboratory
U. S. Environmental Protection Agency
Corvallis, Oregon 97333

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ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CORVALLIS, OREGON 97333

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The National Crop Loss Assessment Network (NCLAN) consists of a group of organizations cooperating in field work, crop modeling, and economic studies to assess the immediate and long-term economic consequences of air pollution on crop production. Two primary objectives are 1) to define relationships between yields of major agricultural crops and doses of ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and mixtures of these pollutants under realistic field conditions, and 2) to use these relationships to assess the economic consequences of exposure of crops to ambient levels of these pollutants throughout the United States. The strategy for completing the economic assessment includes developing and extrapolating a comprehensive set of dose-response data for use in an economic model to estimate effects of crop yield changes on producers and consumers.

This is the sixth annual report of NCLAN, covering the period from 1 February 1985 to 31 January 1986. During this period, research progress has been made in understanding the interacting elements related to air pollution-induced crop loss and integrating them with the economic assessment effort.

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ABSTRACT

The National Crop Loss Assessment Network (NCLAN) consists of a group of organizations cooperating in field work, crop modeling, and economic studies to assess the immediate and long-term economic consequences of air pollution on crop production. Two primary objectives are 1) to define relationships between yields of major agricultural crops and doses of ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and mixtures of these pollutants under realistic field conditions and 2) to use these relationships to assess the economic consequences of exposure of crops to ambient levels of these pollutants throughout the United States. The strategy for completing the economic assessment includes developing and extrapolating a comprehensive set of dose-response data for use in an economic model to estimate effects of crop yield changes on producers and consumers.

This is the sixth annual report of NCLAN, covering the period from 1 February 1985 to 31 January 1986. During this period, research progress has been made in understanding the interacting elements related to air pollution-induced crop loss and integrating them with the economic assessment effort. This was accomplished by developing O_3 dose-crop yield functions for soybean, clover-fescue and alfalfa as affected by soil moisture; and O_3 functions for red clover-timothy and alfalfa as affected by SO_2. Additionally, vertical O_3 gradients over a soybean canopy were established, a data library was developed and data synthesis was initiated. An evaluation of the kriging technique for extrapolating O_3 concentrations across the country and a preliminary national assessment of the economic impact of O_3 on U.S. agriculture are highlighted.

The effects of O_3 and water stress, singly and combined, on the yield of 'McNair 235' cotton was studied in a factorial experiment having six O_3 concentrations and two soil moisture levels with two replicates. Fitting polynomial regression models to the data for soil moisture levels separately indicated a significant linear reduction of seed cotton yield by O_3 in the well-watered plots but no significant relationship was found in the water-stressed plots. Cotton fiber quality was also affected by O_3 and water stress to some extent. Ozone reduced micronaire, color +B, and percent sugar while water stress increased micronaire and percent sugar. In the cotton seeds the fatty acid content was significantly increased by O_3 and the NH_3 content increased by water stress. All of these quality factors are related to the grade of the seed and lint but grade was not significantly affected by the stresses. (Raleigh)[1]

A mixture of ladino clover-tall fescue grown at two soil moisture levels was exposed for a second season (1985) using the same plot-treatment combinations as in 1984. Trends established in 1984 toward decreased growth of clover and increased growth of fescue (possible effect of competition) continued in 1985. Clover growth ceased by the end of the

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[1] Indicates site where research was conducted.

season in all but the charcoal-filtered chambers in which plants were well-watered. Clover stopped growing sooner in high O_3 treatments than in lower O_3 treatments and sooner in moisture stressed than in well-watered plots. Soil moisture did not significantly alter the dose-response relationship for total forage in either year. Estimated loss of total forage for 1985 due to ambient O_3 (seasonal 12-hr/day mean of 0.048 ppm) compared to charcoal filtered air (seasonal 12-hr/day mean of 0.030 ppm) was 11%. (Raleigh)

Field-grown 'Corsoy-79' soybeans were exposed to five O_3 concentrations daily throughout the growing season, and to well-watered and water-stressed conditions during podfill. The results indicated a 23 percent yield reduction due to drought stress and up to a 17 percent yield reduction due to O_3 (0.078 12-hr/day seasonal average). The results suggest a complex interaction between O_3 and H_2O stresses; the 1986 repeat of the study should help to clarify this interaction. (Argonne)

A two-year study designed to determine the interactive effects of O_3 and water stress on alfalfa (Medicago sativa L. cv 'WL-514') was concluded in 1985. The objectives of this study were to develop O_3 dose-yield response functions for this important forage species; to determine how water stress could alter these functions; and to describe the cumulative effects of multiple-year exposures to O_3 on this perennial crop. Field-grown alfalfa, raised under normally-irrigated (NI) or water-stressed (WS) conditions in open-top chambers, was exposed to five O_3 treatments including charcoal-filtered (CF), nonfiltered (NF), and NF plus an additional one-third, two-thirds, or 100 percent of ambient O_3 concentrations (NF x 1.3, NF x 1.7, and NF x 2.0, respectively) during the 1984 and 1985 growing seasons. CF, NF, and non-chambered (AA) plots were replicated three times within each water treatment; NF x 1.3, NF x 1.7, and NF x 2.0 plots were replicated twice. Ambient O_3 concentrations were relatively low in 1985 averaging 0.042 ppm for the seasonal 12-hr (0900-2100) mean from April-October. Water stress reduced total seasonal yield about 27 percent in 1985. Ozone significantly reduced yields in 1985 and the O_3 x water stress interaction was significant (for yield) in May, June, and July when evapotranspiration (ET_o) was greatest. During these months water-stressed alfalfa showed little response to O_3 compared with adequately-watered plants. During later harvests, NI and WS alfalfa responded similarly to O_3. Seasonal yields in NI plots were reduced 0, 14.9, 24.3, and 24.9 percent in NF, NF x 1.3, NF x 1.7, and NF x 2.0 treatments, respectively. Comparable seasonal yield reductions in WS plots were 5.9, 7.2, 13.6, and 18.1 percent. Ozone dose-alfalfa yield loss functions were very similar between 1984 and 1985 and no evidence of cumulative effect of muliple-year exposure to O_3 was found on top growth. However, crown (underground stem) weights were also significantly reduced by O_3. This effect of O_3 on transport or storage of carbohydrate reserves suggests that continued exposure to O_3 could shorten the productive life of alfalfa stands in addition to its effect on yield. (Riverside)

Cotton (Gossypium hirsutum L. cv 'SJ-2') grown in open-top chambers under three different soil moisture regimes was exposed to a gradient of O_3 concentrations ranging from charcoal-filtered (CF) air to nonfiltered (NF) plus 1.5 times ambient O_3 concentrations to determine dose-response relationships between O_3 and cotton raised under a wider range of soil moisture conditions than in previous field experiments. The experiment was conducted at a new field site in Riverside, CA. Because of delays in completing this new facility, the cotton crop was not planted until 16 July and O_3 exposures did not begin until 31 August. Exposures continued for 12 hours daily until 12 November and all plants were harvested on 21-24 November. Mean 12-hr (0800-2000) ambient O_3 averaged 0.055 ppm during the O_3-dispensing season. Foliar O_3 injury was observed on plants in high O_3 treatments given adequate water, but no O_3 symptoms were recorded on plants in the water-stressed treatments. However, O_3 had no statistically significant effect on plant growth or yield. In contrast, the irrigation treatments had significant effects on plant growth and yield. Intermediate and dry plots had 18.3 and 34.0 percent fewer bolls, and 13.6 and 16.2 percent less lint, respectively, than well-watered plants. The interaction between O_3 and irrigation was not statistically significant. The lack of significant yield response to O_3 may have been due to the late maturity of the cotton crop. Boll set occurred in fall, when ambient O_3 was relatively low. However, the irrigation techniques were successful in producing significant differences in plant growth and yield among the three soil water treatments. (Riverside)

A mixed forage stand of red clover and timothy was exposed to four levels of O_3, four levels of SO_2, and all combinations of the two pollutants. The O_3 treatments consisted of charcoal-filtered air, nonfiltered air, and nonfiltered air to which O_3 was added to attain concentrations 1.5 and 2.0 times ambient. Sulfur dioxide exposures simulated the concentration, duration and frequency dynamics associated with point sources. Rates of photosynthesis and oxygen evolution were evaluated in timothy. Sequential harvests were used to evaluate yield and to assess dose-response relationships for the combined species. The O_3 treatments produced greater reductions in photosynthesis as the leaves of timothy increased in age; rates of oxygen evolution increased with exposure to higher concentrations of O_3. The SO_2 treatments had no effect on photosynthesis and only affected oxygen evolution at the highest exposure concentrations. The pollutant treatments had no effect on yield. This was primarily due to the decline of clover in the stand and the dominance of timothy which is less sensitive to both O_3 and SO_2. (Boyce Thompson Institute)

Four hybrids of field corn were exposed to O_3 and/or SO_2 in a replicated split-plot design with seven O_3 and three SO_2 treatments. The O_3 was added daily during a 0700-1900 CST window for the proportional-to-ambient treatments. The SO_2 was added for 3 to 6 hours on 1 to 3 days per week to simulate a point source. The results demonstrated significant hybrid variability in yield response to O_3. One hybrid (Pioneer 3780) had been tested in a 1981 O_3 study at Argonne, and the yield response to O_3 in 1985 was not different. While there was little effect of O_3 alone on any hybrid, the most O_3 sensitive hybrid also exhibited indications of an O_3 x SO_2 interaction. The nature of the interaction was greater sensitivity to O_3 at intermediate SO_2 concentrations. (Argonne)

Two open-top chambers containing a mixed forage crop received O_3 treatments of either nonfiltered air or additions of O_3 to maintain a concentration of twice ambient. The concentrations of O_3 in the chambers were monitored for 12 hours a day (0800 to 2000 h EDT) for a period of 20 days. Measurements of the concentration of O_3 were taken at a rate of 35 observations per hour. The suite of 35 observations was used to calculate the average hourly concentration of O_3 that would have been obtained at rates of 1, 2, 3, 5, 10, and 15 observations per hour. The 1-hr, 12-hr daily, and 12-hr monitoring period average concentrations of O_3 were calculated for each observation frequency. Regression analysis was used to assess the accuracy with which the various observation frequencies estimated the concentrations of O_3. Observation frequencies of two or three per hour provided accurate estimates of the hourly concentration of O_3. The 12-hr daily and 12-hr monitoring period concentrations of O_3 were the same regardless of the frequency of observation. (Boyce Thompson Institute)

An open-top chamber exposed to 2.5 times the ambient O_3 concentration was monitored continuously for two months and the data were analyzed as individual 2-min O_3 readings to simulate a time-share system. Sampling frequencies of three or more per hour appear to provide good estimates of hourly O_3 concentrations. Two samples per hour provide good estimates of 12-hr mean values. Estimating a seasonal 12-hr mean can be adequately done with a single 2-min sample per hour. (Argonne)

The major emphasis over the past year for this project was on data collection and formatting to meet data library specifications. For all sites except Beltsville, data produced from 1980 through 1983 have been collected and formatted. Work over the year has focused on formatting data from 1984-1985 as well as data from the Beltsville site. To ensure data quality, data verification and validation procedures have been adopted. Initial analyses have begun on the combined data. Results of investigations of alternative dose metrics and of a combined (data combined over years for the Raleigh site) soybean analysis are reported. (Raleigh)

Ordinary kriging was used to estimate the monthly mean of the daily maximum 7- and 12-hr O_3 concentrations for the years 1980 through 1984 for each of 68 geographic areas in the United States. As a part of the effort, an assessment was performed to identify whether monthly variograms developed for each geographic region provided acceptable monthly O_3 predictions. It was found that O_3 was spatially distributed, displayed spatial correlation, and exhibited no drift. The kriged 7- and 12-hr values were provided for incorporation into the economic assessment projections. (Corvallis)

A model for predicting the interaction of $O_3 \times H_2O$ on crop yield has been developed to estimate the influence of moisture stress on O_3-caused yield losses over geographic regions. The model predicts reduced O_3 effects in crops which are impacted by moisture stress. While the model is based on O_3 and drought effects reported in the literature, its predictions have not yet been tested against field experiments. Research for 1985 involved a comparison of model predictions with experimental results for soybean from Raleigh, NC, 1984. The work involved calibrating the model to approximate observed O_3 effects on adequately-watered crops and then running the model with water and O_3 inputs from drought-stressed experimental plots. The model tended to underestimate O_3 impacts on moisture-stressed crops, but the difference between the model and observed O_3-response was not statistically significant. (Corvallis)

The NCLAN economics program has as its primary objective performance of an assessment of the economic consequences of O_3 on U.S. agriculture. In preparation for this final assessment in 1987, the NCLAN economic model has been updated to reflect a range of economic, agronomic, and environmental conditions. In addition, issues pertinent to the structure of the economic model were analyzed, including the potential importance of O_3-induced yield variability. Increasing variability in yields due to changes in O_3 implies increased risk for farmers and would require modification of the economic model. Findings from the variability analysis performed in 1985 suggest that O_3 is not causing a consistent, detectable change in the variability of crop yields. While further research on this topic may be warranted, there is insufficient information to warrant the inclusion of O_3 yield (risk) variability in the 1987 economic assessment. (Corvallis)

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SECTION 1

INTRODUCTION

The ozone (O_3) secondary National Ambient Air Quality Standard (NAAQS) is based, in part, on vegetation effects information presented in the U.S. Environmental Protection Agency (EPA) 1978 review "Air Quality Criteria for Ozone and Other Photochemical Oxidants" (1). The most current and indepth review for sulfur dioxide (SO_2) is found in the 1983 U.S. EPA review "Air Quality Criteria for Sulfur Oxides" (2). These reviews illustrated a need for additional field studies of the effects of exposure on economically important crops to support evaluation of the economic impact of O_3 and SO_2 on agriculture. The most current and indepth review for O_3 is found in the 1986 U.S. EPA review "Air Quality Criteria for Ozone and Other Photochemical Oxidants" (3); this review makes use of published NCLAN assessment data through early 1986 (4-11).

The National Crop Loss Assessment Network (NCLAN) is a coordinated national program of field and laboratory studies, crop modeling, and economic assessment efforts initiated by EPA to address the significance of crop losses caused by air pollution and to aid in the establishment and support of the National Ambient Air Quality Standards (NAAQS). The NCLAN research is directed toward understanding the biological effects of air pollution on crops in the ambient environment, and the economic significance of these relationships.

The program has focused primarily on the effects of O_3 on agronomic crops; although some research has incorporated SO_2 in combination with O_3 and several studies were conducted using SO_2 in combination with nitrogen dioxide (NO_2); several horticultural crops have been studied. However, no information has been generated on effects of O_3 on perennial plants (other than forages) including ornamentals, fruits, and forest species.

A Research Management Committee (RMC) represents the five cooperating research programs within the U.S. (Table 1.1.). The RMC plans, manages, and executes the NCLAN Research Program. The program objectives, approach, and organization are discussed in detail in Heck et al. (12-15), Adams and Crocker (16), and Kohut et al. (17).

The NCLAN program components (e.g., regional pollutant dose-yield response evaluations, pollutant/environmental interaction studies, physiological and growth studies, crop loss modeling, and economic modeling) have been coordinated to provide a systematic flow of information needed to conduct a national economic assessment of the effects of air pollutants on U.S. agriculture. A network of four field test sites (Ithaca, NY; Raleigh, NC; Argonne, IL; Shafter, CA) were established in four regions (Northeast, Southeast, Central States, Southwest) that contribute significantly to the production of major crops and have actual or potential pollution problems. At these test sites, normal crop cultural conditions are maintained under ambient and simulated air pollution regimes. In addition, crop modeling and economic assessment programs are situated in the Northwest at Corvallis. From 1981 to 1983, a

Table 1.1. Site locations, regional coordinators, and senior scientists.[a/][b/][c/]

	Site Location	Regional Coordinator	Senior Scientists
1.	Northeast Regional Crop Loss Assessment Program (NERCLAP)	Leonard Weinstein Boyce Thompson Institute Ithaca, NY	Robert G. Amundson Robert J. Kohut John A. Laurence
2.	Southeast Regional Crop Loss Assessment Program (SERCLAP)	Walter W. Heck, USDA/ARS North Carolina State Univ. Raleigh, NC	Allen S. Heagle Virginia M. Lesser Joseph E. Miller
3.	Central States Regional Crop Loss Assessment Program (CSRCLAP)	Lance W. Kress Argonne National Lab Argonne, IL	Patricia M. Irving
4.	Southwest Regional Crop Loss Assessment Program (SWRCLAP)[d/]	O. Clifton Taylor University of California Riverside, CA	Patrick J. Temple
5.	Northwest Regional Crop Loss Assessment Program (NWRCLAP)	David T. Tingey Environ. Prot. Agency Corvallis, OR	Richard M. Adams William E. Hogsett David A. King Allen S. Lefohn Grady E. Neely

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[a/] Program Statistician - John O. Rawlings, Professor of Statistics, Dept. of Statistics, N.C. State University, Raleigh, N.C.

[b/] From 1981 to 1983 a site was operated in Beltsville, MD by USDA/ARS (Howard E. Heggestad and staff). In 1981 and 1982 a site was operated at Tracy, CA by Lawrence Livermore National Laboratory (Gail Bingham and staff).

[c/] The Research Management Committee: Walter W. Heck (Chairman), O. C. Taylor (Assoc. Chairman), Richard M. Adams, Lance W. Kress, David T. Tingey, Leonard H. Weinstein.

[d/] The program has been conducted in Riverside, CA (1980), in Shafter, CA (1981, 1984), and in Tracy, CA (1981, 1982).

fifth site was operated in Beltsville, MD and from 1981 to 1982 a sixth site was operated at Tracy, CA. In 1986, funding limited field operations to only two field sites; Raleigh, NC and Argonne, IL.

The NCLAN field experiments have concentrated on completing O_3 dose-crop yield response data sets for the crop species of greatest economic importance. Data sets have been generated for alfalfa, barley, bean (dry), corn, cotton, mixed forage (Ladino clover/fescue, red clover/timothy), grain sorghum, lettuce, peanut, soybean, tobacco, tomato and winter wheat. A few of these crops have been evaluated over two or more seasons, at more than one site or using one to several cultivars.

Table 1.2. summarizes the O_3 dose-response data which are available from NCLAN. Though the O_3 dose-response data base is now substantial, there is limited replication over years and between sites. Other research in NCLAN (Table 1.3.) and elsewhere has shown that genetic and environmental factors may affect plant response. Extrapolation of the site-specific dose-response data to estimate regional level yield changes introduces a number of uncertainties which cannot yet be quantified. Many cultivars of each crop species may be grown in a region. The NCLAN dose-response data address from one to several cultivars for each crop. Potential extrapolation errors are introduced because the quantitative response of cultivars within a species may be different. The degree of difference in relative sensitivity among cultivars can be estimated experimentally. Thus far, field screening for differential cultivar response to O_3 at a single site and year has only been evaluted for corn and soybean. However, because dose-response curves have been developed for several cultivars of soybean and wheat at different experimental sites in different growing seasons, a preliminary evaluation of the significance of between-year and among-cultivar response differences can be conducted for these crops. Use of the Weibull function for modeling dose-response permits development of combination models which incorporate inherent variations in species response among sites, years, and cultivars.

A second significant source of extrapolative uncertainty results from insuffcient quantitative information describing how the O_3 dose-crop response may be affected by changes in plant water status. Experiments with alfalfa, barley, clover/fescue, cotton, and soybean have provided mixed results. The interaction of water stress with O_3 is complex although it appears that sensitivity to O_3 is reduced under conditions of low soil moisture. However, under conditions of moderate soil moisture stress and the presence of ambient O_3, some NCLAN results with soybean suggest that the effects of these two stresses on yield may be greater than additive. Substantial additional research will be required to fully define these relationships and employ them in NCLAN's economic assessments. Dose-response data for those crops that are not usually irrigated should be collected under several soil moisture regimes. These data would allow consideration of the potential impact of regional variations in soil moisture on the yield loss estimates. Accordingly, field and laboratory soil moisture studies were done through 1985 and were also conducted in 1986. This approach allows the collection of appropriate data for the development of models to describe the effect of soil moisture on O_3 dose-response.

Table 1.2. Crops and cultivars for which NCLAN has developed O_3 dose-response data.[a]

	% of Total U.S. Harvested Acreage (for each crop)	Crop Coverage Sites and Year Grown
Alfalfa	7	
VL-312		Argonne, IL (1984)
VL-514		Shafter, CA (1984, 1985)
Barley	3	
CM-72		Shafter, CA (1983)
Poco		Shafter, CA (1982)
Clover	3	
Ladino clover/Fescue		Raleigh, NC (1984, 1985)
Red clover/Timothy		Ithaca, NY (1984, 1985)
Corn	23	
PAG 397		Argonne, IL (1981)
Pioneer 3780		Argonne, IL (1981, 1985)
FR20A x FR634		Argonne, IL (1985)
FR20A x FR35		
FR23 x LH 74		
Cotton	3	
Acala SJ2		Shafter, CA (1981, 1982) Riverside (1985)
Stoneville 213		Raleigh, NC (1982)
McNair 235		Raleigh, NC (1985)
Grain Sorghum	4	
A28+		Argonne, IL (1982)
Kidney bean	<1	
California Light Red		Ithaca, NY (1980, 1982)
Lettuce	<1	
Empire		Shafter, CA (1983)
Peanut	<1	
NC-6		Raleigh, NC (1980)
Soybean[b]	20	
Davis		Raleigh, NC (1981, 1982, 1983, 1984)
Young		Raleigh, NC (1986)
Hodgson		Ithaca, NY (1981)
Williams - 79		Beltsville, MD (1981, 1982, 1983) Argonne, IL (1983)
Corsoy - 79		Argonne, IL (1980, 1983, 1985, 1986) Beltsville, MD (1983)
Essex		Beltsville, MD (1981)
Forrest		Beltsville, MD (1982)
Amsoy - 71		Argonne, IL (1983)
Pella		Argonne, IL (1983)
Tobacco	<1	
McNair 994		Raleigh, NC (1983)

Table 1.2. (cont'd)

	% of Total U.S. Harvested Acreage (for each crop)	Crop Coverage Sites and Year Grown
Tomato	<1	
Jet Star		Beltsville, MD (1980)
Murietta		Tracy, CA (1981, 1982)
Wheat	22	
Abe		Argonne, IL (1982, 1983)
Arthur - 71		Argonne, IL (1982, 1983)
Roland		Argonne, IL (1982)
Vona	—	Ithaca, NY (1982, 1983)
Total	87	

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[a] Source: USDA, Agricultural Statistics. 1984 (from the 1982 production year); kidney bean is value for all dry bean; clover and timothy are no longer determined - were about 3% in 1970.

[b] Soybean was done at Raleigh, NC (cv Young) and Argonne, IL (cv Corsoy-79) in 1986.

Table 1.3. NCLAN field experiments involving interactions of genetic and environmental factors and O_3 dose-response.

Crop/Cultivar	Year	Site
Cultivar Sensitivity Ranking		
Corn (14 hybrids)	1981	Argonne, IL
Soybean		
Williams-79, Pella, Corsoy-79, Amsoy-71	1983	Argonne, IL
Interactions: O_3 and Soil Moisture		
Alfalfa, WL-514	1984, 1985	Shafter, CA
Barley, CM 72	1983	Shafter, CA
Cotton		
Acala SJ2	1981, 1982	Shafter, CA
Acala SJ2	1985	Riverside, CA
McNair 235	1985	Raleigh, NC
Ladino Clover/Fescue	1984, 1985	Raleigh, NC
Soybean		
Williams-79, Forrest	1982	Beltsville, MD
Williams-79, Corsoy-79	1983	Beltsville, MD
Corsoy-79	1985, 1986	Argonne, IL
Davis	1983, 1984	Raleigh, NC
Young	1986	Raleigh, NC
Interactions: O_3 and SO_2		
Alfalfa, WL-312	1984	Argonne, IL
Corn	1985	Argonne, IL
Pioneer 3780		
FR20A x FR634		
FR20A x FR35		
FR23 x LH74		
Cotton		
Stoneville 213	1982	Raleigh, NC
Red Clover/Timothy	1984, 1985	Ithaca, NY
Soybean		
Davis	1981	Raleigh, NC
Williams-79	1981, 1982	Beltsville, MD
Essex	1981	Beltsville, MD
Forrest	1982	Beltsville, MD
Amsoy-71	1983	Argonne, IL
Corsoy-79	1983	Argonne, IL
Tomato		
Jet-star	1980	Beltsville, MD
Murrieto	1981, 1982	Tracy, CA
Wheat		
Vona	1983	Ithaca, NY

Table 1.3. (con'td)

Crop/Cultivar	Year	Site
Ozone Exposure Dynamics		
Soybean		
Davis	1982	Raleigh, NC
Tobacco		
McNair 944	1983	Raleigh, NC

Other air pollutants may interact with O_3 to modify dose-response relationships, although the importance of these interactions to agriculture has not been fully elucidated. Experiments to date (Table 1.3.) suggest that these interactions may yield statistically significant results, but assessing their importance in affecting crop losses will require new techniques and additional experimentation.

Two important assumptions must be made in applying the biological data to the national economic assessment: 1) all economically-important cultivars of species in aggregate respond similarly to those tested; and 2) environmental conditions differing from those in field experiments would not significantly affect the aggregate estimate of plant response to O_3. The validity of these assumptions is being tested with available data.

This report presents results from 1985 research. The results include the biological dose-response data for O_3 and data concerning the modification of these responses by two environmental variables (soil moisture and SO_2). In addition, the efforts to develop a soil moisture/O_3 model and the application of NCLAN data to an evaluation of the economic consequences of O_3 air pollution for U.S. agriculture are further discussed. We have included an update on the Data Synthesis and Extrapolation program and on the kriging method to extrapolate O_3 data into rural areas. Lastly, we have included a listing of NCLAN publications not contained in the 1984 Annual Report.

SECTION 2

CONCLUSIONS

Analysis of variance across both soil moisture treatments indicated that O_3, but not water stress, significantly reduced the yield of 'McNair 235' cotton. The polynomial regression model for combined soil moisture levels indicated a significant linear reduction of seed cotton yield by O_3 (PR>0.01). The O_3*H_2O interaction term was significant indicating that H_2O stress did modify the yield-response to O_3. A test of homogeneity for the Weibull models did not indicate an O_3*H_2O interaction. This is not necessarily inconsistent with the results of the polynomial, since the Weibull is testing a curvilinear relationship while the polynomial model indicated a linear effect of O_3. Cotton fiber quality was also affected by O_3 and water stress. Ozone reduced micronaire, color +B, and % sugar while water stress increased micronaire and % sugar. The data suggest that O_3 promotes the maturity of cotton while water stress retards it. In the cotton seeds, the fatty acid content was significantly increased by O_3 and the NH_3 content increased by water stress. Both of these are related to the grade of the seed, but grade was not significantly affected by the stresses. (Raleigh)

A mixture of ladino clover and tall fescue is one of the most important forage crops in the southern United States. However, this crop routinely suffers from a decline in clover production after the first year of growth which decreases quality of the forage. NCLAN results from a 2-year study in Raleigh, NC indicate that O_3 can contribute to this decline. A field-grown mixture of ladino clover and tall fescue was exposed for two growing seasons to chronic doses of O_3 in open-top field chambers which allowed control of O_3 concentrations throughout the season. Regression models using the 1985 results indicated an 11 percent yield loss of the forage mixture at ambient levels of O_3 found near Raleigh, NC. The comparable value for 1984 was 9 percent. The O_3 effects were similar at two levels of soil moisture for both years (well-watered and moderately stressed). Clover showed extensive injury at ambient levels of O_3 and was much more sensitive than the fescue which showed injury only at the highest O_3 levels. At low doses of O_3, there was still a greater yield of clover than of fescue. At the highest dose of O_3, fescue out-yielded clover, probably because of O_3-induced growth decline of clover which decreased competition and allowed the more resistant fescue to grow more rapidly. By the end of the 1985 season, growth of clover had essentially ceased in all but the CF adequate moisture treatment. (Raleigh)

Data from Argonne suggest that moisture stress reduces C-fixation in leaves, but increases C-allocation to the roots of soybeans. The drought-induced stimulation of root growth is apparently suppressed by the O_3 exposure. Conversely, the irrigated plots exhibited greater sensitivity to O_3 in above-ground vegetative biomass accumulation. Perhaps repair processes due to O_3 exposure result in the utilization of C that would otherwise have been allocated to fine root growth in water-stressed plants while irrigated plants are depleted of shoot biomass C as a result of repair processes. Bean yields were reduced (compared to the CF treatment) by O_3 more in the non-stressed than the water-stressed treatments. However, the water-stressed CF treatment had severely reduced top growth and yield, which the O_3-treated and water-stressed plots did not. Using the NF treatment yield as the control yield, the drought-stressed plant yields were reduced more by O_3 than the non-stressed plant yields. The results suggest a complex interaction between H_2O and O_3 stresses that may take years to define. (Argonne)

A 2-year study of the interactive effects of O_3 and drought stress on alfalfa was concluded in 1985. Ambient O_3 concentrations were relatively low in Shafter in 1985 and only two hourly means above 0.10 ppm were recorded between 23 March and 9 October. Seasonal 12-hr mean O_3 averaged 0.042 ppm for this period, during which alfalfa was harvested seven times. Exposure to added O_3 had no effect on water use by alfalfa but water use efficiency in both water-stressed and non-stressed plots were reduced by increased exposures to O_3. Both O_3 and drought stress significantly reduced seasonal yield of alfalfa, but the interaction between O_3 and irrigation level was not statistically significant. Crown weights were also reduced by O_3 and drought stress, but the interaction between the two stresses was not significant. Comparison of relative yield responses of alfalfa to O_3 in 1984 and 1985 indicated that alfalfa responded to O_3 similarly in both years, and the relative response between well-watered and drought-stressed alfalfa was also similar in both years. No evidence of residual effects of the previous year's exposure to O_3 was observed on alfalfa yields in 1985. (Riverside)

Well-watered cotton ('SJ-2') exposed to elevated O_3 levels in Riverside, CA, developed severe foliar injury symptoms, but plants in the severely water-stressed treatment did not develop O_3 injury symptoms. Ozone had no effect on yield in any of the irrigation treatments, possibly because boll set occurred in fall, when ambient O_3 concentrations were relatively low. Irrigation level had significant effects on plant water status, plant growth, and yield, but the interaction between O_3 and irrigation was not statistically significant. The significant differences in plant water status and growth among the three soil moisture treatments suggests that a calibrated drip-tape irrigation system can be employed successfully in a factorial experiment to test the interactive effects of multiple levels of O_3 and soil moisture on plant growth and yield. (Riverside)

In two years of study on the effects of O_3 and SO_2 on red clover and timothy, it was found that O_3 reduced photosynthesis and increased oxygen evolution in both species, but that the effects were most pronounced on clover. Exposure to SO_2 produced reductions in photosynthesis only at relatively high concentrations (greater than 0.70 ppm). There were no measurable interactions between the two pollutants in affecting either photosynthesis or oxygen evolution. Although there was a reduction in yield attributable to O_3 in the first year of the study, this reduction in yield was not observed in the second year. The lack of yield effect in the second year can be attributed to three factors operating in concert: a high degree of heterogeneity in stocking and composition in the stand's second year, a general decline in clover in the stand as is expected in the second year, and the dominance of the more O_3-resistant timothy in the stand. Collectively, these factors resulted in a highly variable stand of forage dominated by a species not sensitive to O_3. Consequently, no statistically significant reductions in yield were produced by the pollutant treatments in 1985. It appears that for O_3 to have an impact on the yield of a mixed forage crop of clover and timothy, clover must constitute a major portion of the stand. (Boyce Thompson Institute)

The responses of hybrid corn to O_3 observed in this study were similar to those observed previously at Argonne (9). However, the test for heterogeneity of field response to O_3 among the four hybrids was significant, while in the early study the two cultivars showed a homogeneous response. There appeared to be little effect of SO_2 alone on yield, but SO_2 tended to cause greater O_3-induced yield reductions, and reduced the apparent "plateau" effect in O_3 response. The most O_3-sensitive hybrid (FR20A x FR35) also exhibited an apparent (but non-significant) O_3 x SO_2 interaction such that the O_3 caused greater yield reduction at the intermediate SO_2 dose (9.31 ppm-hrs) than at the ambient (2.86 ppm-hrs) or the high (19.46 ppm-hrs) doses. (Argonne)

The analysis of time-share monitoring indicated that observation frequencies of two or three per hour generally provided accurate estimates of the hourly concentrations of O_3. The reliability of the estimates was a function of the concentration of O_3 and the rate at which the concentration changed from hour to hour. The daily mean concentration and monitoring period 12-hr mean concentrations of O_3 were the same, regardless of the number of observations per hour. These analyses indicate that daily or longer dose statistics used to characterize the exposure regimes in NCLAN studies are accurately defined at sampling frequencies of one or two times per hour and that hourly maxima are accurately defined by three or more times per hour. (Boyce Thompson Institute)

Two or three 2-minute samples per hour usually provide good hourly and daily estimates of O_3 concentration. Since the yield loss estimates generated in the NCLAN program use a seasonal estimate of O_3, the time-share monitoring concept with sampling frequencies as low as one per hour appears to be a valid method of providing accurate estimates of O_3 concentration. (Argonne)

All O_3 (22 units), sulfur dioxide (8 units), and oxides of nitrogen (1 unit) analyzers performed excellently or satisfactorily in this year's performance audits. Weight checks indicated mean accuracy was at least 99.89 percent at all locations. Leaf area calibration measurements revealed mean accuracy was at least 98.27 percent at all sites. Systems evaluations showed each location was in compliance with NCLAN quality assurance documentation requirements. Comments made in the report were "to improve a good program." (Corvallis)

Analyses investigating alternative dose metrics have suggested that the 7-hr component (1000-1700 DT) of the 12-hr dispensing day is more important than the remaining 5 hr in the plant's response to O_3. In addition, these preliminary results from both the 1982 and 1983 studies suggested nearly equal weighting be given to all O_3 occurrences (i.e., peak and non-peak occurrences). Results of the residual analysis exemplifies the types of analyses proposed on all NCLAN data for the various crops. For each crop, the sequence of analyses will involve investigating the homogeneity of variances over sites and years, investigating types of transformations which could stabilize variance and minimize the residual sums of squares, and development of final dose-response models. (Raleigh)

The technique of ordinary kriging was used to predict the monthly mean of the daily maximum 7- and 12-hr mean O_3 concentrations within each of 68 geographic areas. Prior to performing the air quality characterization, it was necessary to demonstrate that monthly variograms produced for each geographic region provided acceptable monthly O_3 predictions. Verification was obtained, and it was found that O_3 was spatially distributed, displayed spatial correlation, and exhibited no drift. (Corvallis)

A test of the O_3 x H_2O interaction model for soybean showed no significant difference between model predictions and the observed response to O_3 with drought stress, although the model tended to underestimate O_3 impacts on drought-stressed soybean (i.e., the model tended to overestimate the O_3 x H_2O interaction). This result for soybean is different from that expected for cotton, where experimental results indicate a substantial reduction of sensitivity to O_3 caused by moisture stress. Current studies of O_3 x H_2O should aid in evaluating the tendency of the model to overestimate the interaction for soybean. (Corvallis)

Progress under the economic component of NCLAN included work in updating the basic NCLAN economic model of the U.S. agricultural sector. The updating gives the model flexibility to address a range of economic conditions that may exist in 1987, including changes in the structure of domestic and foreign markets, farm input and output relationships, as well as changes in agronomic and environmental conditions faced by agriculture. The model was also modified to include the effects of O_3-induced changes in supply on U.S. farm programs. In addition to updating the model, the issue of O_3-induced increases in crop variability and attendant implications for risk incurred by U.S. farmers was also evaluated. Findings from these analyses indicated that O_3 does not appear to be associated with any directly observed increase in the variability in crop yield for the NCLAN crops. As a result, it was decided the NCLAN economic model would not be modified to include elements of O_3-related risk within the final economic assessment. (Corvallis)

SECTION 3

RECOMMENDATIONS

The results of NCLAN research suggest that a better understanding of the influence of selected biotic and abiotic variables on the O_3 dose-response relationships is needed. Factors considered to be important include soil moisture status, the dynamics of pollutant exposure, cultivar variability, other pollutants, insects and diseases. Additionally, other crops, including ornamentals and perennials, should be studied. Assessment of the influence of these variables on O_3 dose-response functions will increase the accuracy of and confidence in the regional and national crop loss estimates and the economic assessments. To achieve these important additions to our understanding of dose-response relationships and economic analyses, the following recommendations for priority research are made. These should be considered by EPA in future research programs dealing with crops.

1. It is important to understand the effects of soil moisture stress on yield response to O_3. These effects should be incorporated into dose-response functions and into models that relate soil moisture stress to effects of O_3 on soybean and other crops; both of these efforts should be utilized in future economic loss assessments. Soil moisture stress studies should be conducted in the field using rainfall exclusion systems to allow more accurate control of soil moisture. However, initial studies in greenhouse and controlled environment facilities would be of high value. The studies should include three or more soil moisture levels. Selected research should incorporate similar moisture stress treatments at different stages of plant growth.

2. The biological data synthesis and analysis program utilizing the NCLAN data base needs to be a continuing effort for the NCLAN and other data bases. This facilitates testing of new concepts and statistical models for predicting regional/national crop losses. Improved predictions can then be incorporated into economic assessment efforts. This program should insure that a complete library of NCLAN and other data will be available for use by other scientists.

3. The influence of various components of the O_3 exposure regime (e.g., concentration, exposure duration, and exposure frequency) on plant response should be evaluated to permit a better understanding of pollutant exposures and how they relate to plant effects. Assessing exposure and dose characterizations and their relationships to yield losses will provide important information for setting secondary air quality standards. This research is supportive of that recommended in (2) above.

4. Cultivar screening to evaluate the degree of variability within a crop species should be initiated (several studies of a few cultivars for soybean and wheat are completed). Results from these designs should be used to assess the range of sensitivity

within a species. Results should be used to develop a range of expected crop losses for each species. This could result in major changes in loss assessments.

5. Pollutant/pest interactions should be evaluated to assess the potential roles of air pollutants in altering disease epidemiology and insect population dynamics. Modification of insect and disease-induced crop losses by air pollutants could have a significant impact on national economic crop loss values.

6. Experiments to evaluate the effects of SO_2 exposure on O_3 dose-response functions should continue. Research is needed on the influence of NO_2 on plant growth and yield as NO_2 affects plant response to O_3 and SO_2.

7. Research on the effects of O_3 on yields of perennial crops such as grapes and apples and on the growth and marketability of ornamentals should be initiated. These crops are of considerable economic importance in their production areas and the regional consequences of pollutant-induced losses could be significant. Additionally, high value truck crops (i.e., bean, melon, potato) should be further studied.

8. The exposure dynamics of the field experimental designs from NCLAN should be calibrated since the NCLAN program moved from a 7-hr constant and proportional O_3 additions to a 12-hr proportional addition regime. This is a critical component that will provide a melding of the constant and proportional types of data and permit a better understanding of the best experimental exposure approach. The NCLAN program has compared the 7-hr constant, 7-hr proportional and 12-hr proportional using tobacco in 1983; a comparision of the 7-hr constant and 7-hr proportional was completed for soybean in 1982; these are the only available data sets.

9. Additional refinements (i.e., environment and edaphic effects) to the crop loss modeling effort should be explored. To the extent feasible, methodologies used in large area crop production forecasting should be incorporated into the models.

10. The scope of the national economic model should be expanded to accommodate a wider range of O_3-yield related issues. Alternative moisture stress scenarios and a less time-specific base model will increase the generality of the model. Other issues, such as the effects of O_3 on yield variability, have important economic implications and should be tested and, if significant, incorporated in economic assessments of O_3.

The first priority area (soil moisture x O_3) was incorporated into the final (1986) NCLAN research program (Table 3.1.). Although critical areas for crop assessment, the other areas will not be incorporated into the NCLAN program. All of these priority research areas should be seriously considered in subsequent EPA research efforts. Final summary plans for the NCLAN program are shown in Table 3.2.

Table 3.1. Summary of 1986 NCLAN field experiments.

Location	Design	Species Cultivar
Southeast		
Raleigh, NC	O_3 - Soil Moisture (Physiology and Yield)	Soybean, Young
Central States		
Argonne, IL	O_3 - Soil Moisture (Yield, some Physiology)	Soybean, Corsoy - 79

Table 3.2. Final summary plans for NCLAN.

Activity	Time	Location
Summarize all field data, prepare for publication	1986-1987	All field sites
Complete data bank	1986	Raleigh, support from all field sites
Complete data synthesis across NCLAN	1986-1987	Raleigh
Complete soil moisture modeling effort	1986-1987	Corvallis
Final O_3 air quality data	1986-1987	Corvallis
Complete economic assessment	1986-1987	Corvallis
International conference	Oct. 25-29, 1987	Raleigh, support from all sites
Publication of proceedings	1988	Raleigh, Riverside, Corvallis

SECTION 4

RESPONSE OF CROPS TO O_3

4.1. Soil Moisture/O_3 Dose-Response Relationships

4.1.1. The Influence of Ozone on Cotton Yield Under Well-Watered and Water-Stressed Conditions (SERCLAP)--J. E. Miller, A. S. Heagle, R. P. Patterson, W. A. Pursley and S. L. Corda

4.1.1.1. Introduction

Present evidence suggests that cotton is sensitive to O_3 at levels that occur in ambient air where cotton is grown. Several studies have compared yield of cotton grown in air where O_3 was partially removed by charcoal filtration (CF) with yield of cotton grown in nonfiltered air (NF). In a greenhouse study at Beltsville, MD, yields of important cultivars such as 'Acala SJ-1' and 'Stoneville 213' were 12 to 14 percent less in NF air than in CF air while yield of the cultivar 'Deltapine Smooth Leaf' was decreased by 31 percent in NF air (18). At Parlier, CA in the San Joaquin Valley, yield of 'Acala SJ-2' cotton grown in field chambers with partial air filtration (1/3 CF), NF air, or NF air with O_3 added (to achieve twice the NF concentration) was 5, 15 and 33 percent less, respectively, than that in CF air (19). These studies indicated that cotton yield was decreased by levels of O_3 in ambient air in the East and West and showed the need to determine the relationship between O_3 doses and cotton yield responses.

Ozone dose-yield response experiments performed with irrigated 'Acala SJ-2' cotton grown in open-top field chambers at Shafter, CA in 1981 and 1982 (11) showed that ambient levels of O_3 can decrease cotton yield from 15-20 percent. In both years of this study the influence of water stress on the yield response to O_3 was evaluated. In 1981, in the sub-optimally irrigated plots, the yields were substantially reduced by water stress, but there was very little response to O_3. In 1982, even though irrigation regimes were similar, the water-stressed plots responded to O_3 similarly to the normally irrigated plots. This difference between years was attributed to the dry conditions with high evaporative demand in 1981 contrasted to the cool moist conditions of 1982. In 1981 there was probably little O_3 uptake due to stomatal closure, while in 1982 even sub-optimum soil water might not have caused marked closure allowing O_3 uptake.

In Raleigh, NC open-top chamber experiments showed that yields of 'Stoneville 213' cotton were reduced 11, 23, 30 and 55 percent below CF plots (0.026 ppm) by seasonal 7-hr O_3 concentrations of 0.058, 0.072, 0.085 and 0.104 ppm, respectively (20). While this variety of eastern cotton shows similar sensitivity to O_3 as the western 'Acala SJ-2' with adequate soil moisture, nothing is currently known concerning the influence of water stress on the O_3 dose-response and whether eastern cotton will react similarly to the western variety.

The objectives of this study were to: 1) measure the effects of a range of chronic doses of O_3 on yield and quality of an additional eastern cotton cultivar and 2) determine the extent that water stress modifies these relationships.

4.1.1.2. Materials and methods

Cultural practices and conditions. The experiment was performed approximately 9 km south of Raleigh, NC in a field consisting of about 30 cm of Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudult) overlaying an Appling sandy loam (clayey, kaolinitic, thermic Typic Hapludult). The field was fertilized and limed according to soil test recommendations and herbicides and pesticides applied as listed in Table 4.1.1.1.

Cotton (Gossypium hirsutum L. cv. 'McNair 235') was planted in rows oriented in a north-south direction at a density of 46 seeds m^{-1} with a 51-cm row spacing on 29 May 1985. The plants emerged on 5 June and plots were selected on 11 June based on estimates of stand uniformity. At that time the plots were thinned to 11 plants m^{-1} of row in the designated yield rows. Initially, there were three rows in each chamber (51-cm row spacing). The center rows were used for another study and removed by 29 July before significant canopy closing occurred (leaving a 102-cm row spacing). The yield row segments reported in this study were the northern 1-m row sections in each of the two remaining rows (separated from the chamber wall by a 50-cm buffer of plants).

Experimental design. The experiment was a completely randomized factorial design consisting of six O_3 concentrations and two soil-moisture regimes. There were two replicates of each combination of treatments accounting for the total of 24 plots. Four of the plots were ambient air (AA) which were not chambered (two for each soil moisture treatment). The target O_3 concentrations in the chambers were charcoal-filtered (CF), non-filtered (NF), NF x 1.2 , NF x 1.4 and NF x 1.7 (proportional ratios with respect to the NF plots). The two soil moisture regimes were well-watered (WW) and water-stressed (WS).

Pollutant treatment. Chamber frames were installed on 20 plots on 18 June and the panels attached on 26 June. Dispensing was started on 28 June. Ozone treatments were administered from 0800-2000 EST when the ambient concentration exceeded 0.03 ppm. All O_3 additions were made in proportion to the ambient O_3 levels by use of the "NCLAN proportional controller". Ozone was added daily (with the exception of those times shown in Table 4.1.1.2.) through 30 October at which time the plants in all plots had reached physiological maturity.

Soil moisture regimes and irrigation treatments. The two soil moisture regimes were established by applying irrigation at different frequencies throughout the growth period. The "target" soil moisture criteria that triggered irrigation were: -0.1 MPa soil matric potential for the WW plots and -0.3 MPa for the WS plots. Irrigation (approximately 2.5 cm delivered in 2 hr) was applied with drip tubing located at the base

Table 4.1.1.1. Chronology of activities in the cotton study at Raleigh, NC in 1985.

Month	Day	Event
February	25	Field disced.
	27	Pre-season soil samples taken for nutrient analysis.
March	1	Pre-season soil samples taken for nematode analysis.
April	12	Field chisel ploved. 934 kg ha^{-1} dolomitic lime applied to field. 748 kg ha^{-1} (6-6-18) fertilizer applied to field.
	17	Field disced.
May	6	Cotoran 80WP(ovex) (1.1 kg ha^{-1}) and Treflan (4EC(trifluralin) (1.2 l ha^{-1}) tank mix applied to field. Field disced. Planted cotton cv. McNair 235 (33 seeds m^{-1}) and applied Temik TSX 10G (5% aldicarb, 10% terrachlor, 2.5% terrazol)(2.8 kg ha^{-1}), at a depth of 1-inch.
	13	Emergence of cotton plants.
	22	Initial thinning of cotton seedlings to 1-inch spacing.
	28	Field disced under due to poor stand resulting from *Rhizoctonia* infection.
	29	Replanted McNair 235 cotton seed (46 seeds m^{-1}) with Temik TSX 10G (16 kg ha^{-1}). Rows 51 cm apart, seed 2.5 cm deep.
June	5	Emergence of cotton plants.
	11	Plots chosen. Cotton seedlings thinned within plots to 11 plants m^{-1} of row.
	18	Chamber frames in place.
	26	Top and bottom panels installed on chamber frames on all plots.
	28	First day of dispensing (0800 EST-2000 EST).

Table 4.1.1.1. (cont'd)

MONTH	DAY	EVENT
July	10	Irrometers installed. Neutron probe access tubes installed. Soil samples taken for soil moisture release curve data.
	12	Applied Pounce 3.2E (permethrin)(6.3 cc l^{-1}) to all plots.
	18	Two outside rows of cotton in each plot removed.
	24	Applied tank mixture of Pounce 3.2E(6.6 cc l^{-1}) and Cygon 2-E (dimethoate)(6.3 cc l^{-1}) to all plots.
	31	Applied Roundup (glyphosate)(7.1 cc l^{-1}) in field outside of all plots.
August	2	Applied Pounce 3.2E (permethrin)(6.3 cc l^{-1}) to all plots. Subsequent applications at same rate.
	7	Applied permethrin.
	14	Applied Capture 2EC (3.1 cc l^{-1}) to all plots. Subsequent applications at same rate.
	21	Applied Capture.
	28	Applied Capture.
September	12	Applied permethrin.
	30	First harvest of seed cotton from open bolls.
October	7	Second harvest of seed cotton.
	15	Third harvest of seed cotton.
	24	Fourth harvest of seed cotton.
	30	Last full day of dispensing (0800-2000 EST). Fifth harvest of seed cotton.
November	5	Sixth harvest of seed cotton. Harvested cotton shoots from plots 1-12.
	6	Harvested cotton shoots from plots 13-24.
	18	Post-season soil samples taken for nutrient analysis.

Table 4.1.1.2. Dates and hours of suspended O_3 dispensing.

		Hours of Suspended Dispensing Due to	
Month	Day	System Malfunction	Line Calibration
July	8	1.0	
	28	4.5	
	30		3.0
	31		3.0
August	1	7.0	
	5	5.0	
	9	0.5	
	11	1.0	
	19		3.5
	20		7.0
	23	2.5	
	26	5.0	
	31	10.0	
September	19		4.0
	24	2.5	
	25	2.0	
	26	5.0	
Total Hours		46.0	20.5
Seasonal Percent of time down[a]		3.0	1.4

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[a] Seasonal total calculated as 126 days x 12 hours/day = 1512 hours (June 28 - October 30).

of each row of plants. Soil moisture measurements were made in all plots with a neutron probe at a depth of 22.5 cm. Irrigation dates are shown in Table 4.1.1.3.

Response measurements. Cotton from each 1-m of row was hand-picked on 30 September, 7, 15, 24, 30 October and 5 November. At each harvest date only loose (mature) cotton was picked from opened bolls. After oven drying the weight of unginned cotton and number of bolls were determined from each harvest and then the samples from each plot were pooled. A 500-g sub-sample of cotton was taken from each pooled sample and ginned. The percentage of lint and seed were determined and these were analyzed for quality factors, by the USDA Cotton Division in Clemson, SC.

Statistical Analyses. Yield data were analyzed by analysis of variance (ANOVA) to test for position effects within the plots. Position (NE or NW row segment) effects were significant but there was no interaction with the O_3 or soil moisture treatments. Subsequent analyses used the pooled data for each plot. ANOVA's were then run on the combined data to test for effects of O_3, soil moisture level, and their interaction. ANOVA's were also run for each soil moisture treatment separately to test for O_3 effects within each of the soil moisture regimes. Polynomial and Weibull dose-response models were fit to the chamber yield data for soil moisture levels separately and combined. Lack of fit tests were calculated for the linear models and tests of shape for the Weibull models. Lint and seed quality factors were analyzed by ANOVA for the WW and WS chambered-plots combined.

4.1.1.3. Results and Discussion

Pollutant doses. During the experimental period the AA plot O_3 concentrations (mean seasonal 12 hr d^{-1}) averaged 0.044 ppm. The concentrations in the chambered plots (combined for soil moisture treatments and replicates) were 0.022, 0.041, 0.051, 0.061 and 0.073 ppm for the CF, NF, NF x 1.2, NF x 1.4 and NF x 1.7 treatments, respectively (Table 4.1.1.4.). The highest ambient 1-hr peak was 0.119 ppm which is very close to the Secondary Standard of 0.12 ppm for O_3 (Table 4.1.1.4.). The 1-hr standard was not exceeded in the NF plot but was in all three treatments receiving O_3 additions. The daily 12-hr and 24-hr mean O_3 concentrations show the typical pattern of periodic episodes usually lasting three to seven days before dissipating due to changes in weather patterns (Figure 4.1.1.1.). The peak 12-hr mean concentration was approximately 0.09 ppm and 12-hr means of 0.07 ppm or greater occurred on eight days. The mean-seasonal diurnal O_3 concentration patterns illustrate that the 12-hr O_3 addition coincides quite well with the daily period of elevated O_3 (Figure 4.1.1.2.).

Soil Moisture. The soil matric potential in the WW plots was less than the target minimum (-0.1 MPa) on one occasion (Table 4.1.1.5.). This occurred due to the very rapid depletion of moisture in the sandy surface soil due to hot dry conditions. It was necessary to irrigate the WW plots 11 times. Wilting was apparent only on 19 July in the WW plots. In the WS plots there were eight cycles in in which significant soil moisture

Table 4.1.1.3. Dates of irrigation.

Dates Irrigated			Soil Moisture Treatment[a/] Well Watered	Water-Stressed
July	19		X	
August	9		X	
	13		X	X
	16		X	
September	5		X	
	6		X	X
	11		X	
	13			X
	16		X	
	20		X	X
	30		X	
October	18		X	
		TOTAL	27.5 cm	10

[a/] Cotton was irrigated at a rate of 2.5 cm in 2 hr. Water was applied using drip tubes adjacent to each plot row.

Table 4.1.1.4. Seasonal, highest, and second highest 1-hr and 12-hr mean O_3 concentrations.[a/]

Soil Moisture Treatment	Ozone Treatment	12-hr/day values[a/] ppm		1-hr/day peak values[b/] ppm	
		Seasonal Mean	Highest	Seasonal Mean	Highest
Well-Watered	CF	0.020	0.045	0.028	0.062
	NF	0.041	0.094	0.055	0.118
	NF x 1.2	0.050	0.134	0.069	0.166
	NF x 1.4	0.060	0.174	0.086	0.225
	NF x 1.7	0.071	0.217	0.106	0.290
	AA	0.043	0.089	0.057	0.110
Water-Stressed	CF	0.023	0.052	0.032	0.061
	NF	0.040	0.098	0.054	0.109
	NF x 1.2	0.051	0.132	0.071	0.162
	NF x 1.4	0.062	0.172	0.090	0.222
	NF x 1.7	0.074	0.223	0.110	0.281
	AA	0.045	0.092	0.059	0.119

[a/] Values are the mean of two replicates.

[b/] The 1-hr/day peak value is defined as the largest mean of two consecutive 3-minute samples taken at 45-minute intervals.

Table 4.1.1.5. Soil matric potential readings at 22.5 cm depth.[a]

Date		VW Plots (-MPa)	WS Plots (-MPa)
July	10	0.02	0.01
	19	0.11	0.10
	22	0.03	0.19
	30	0.01	0.01
	31	0.01	0.01
August	9	0.07	0.06
	13	0.04	0.34
	14	0.01	0.03
	16	0.03	0.07
	20	0.01	0.06
	23	0.01	0.10
	29	0.01	0.01
September	4	0.09	0.10
	6	0.02	0.19
	9	0.01	0.03
	11	0.06	0.11
	13	0.01	0.33
	16	0.05	0.04
	18	0.02	--
	20	0.03	0.30
	25	0.01	--
	27	--	0.05
	30	0.06	0.20
October	1	0.01	0.34
	7	0.01	0.03
	10	0.01	0.05
	14	0.03	--
	15	--	0.22
	17	0.05	0.27
November	7	0.01	0.01

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[a] Values are the average measurements in six to eight plots in each soil moisture treatment.

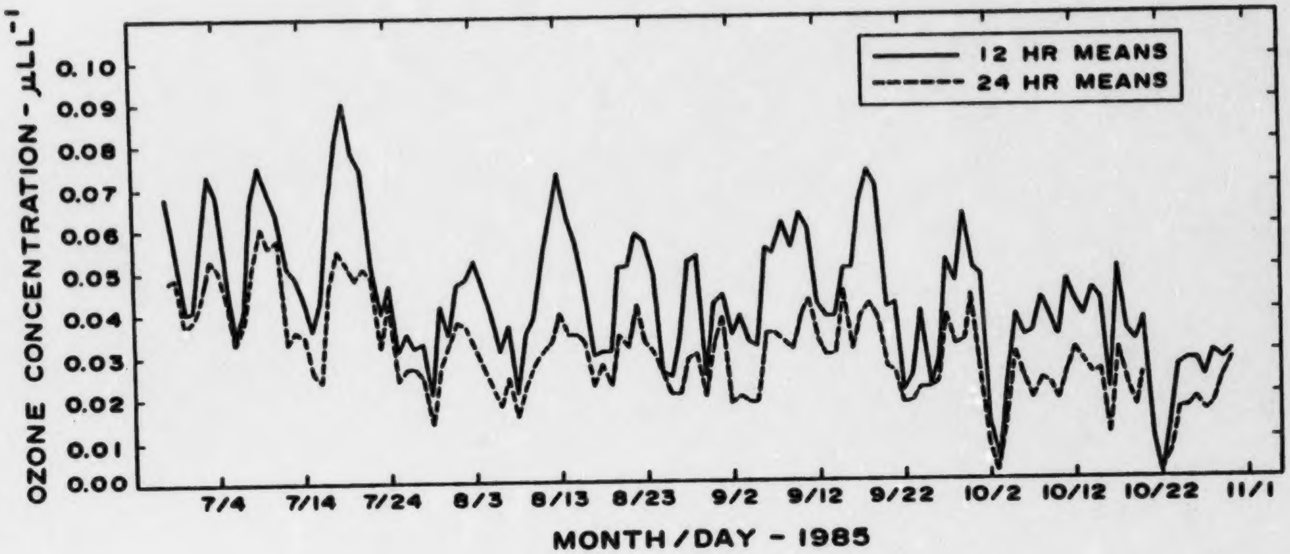

Figure 4.1.1.1. Daily 12- and 24-hr O_3 concentrations from 28 June - 30 October 1985 at Raleigh, NC.

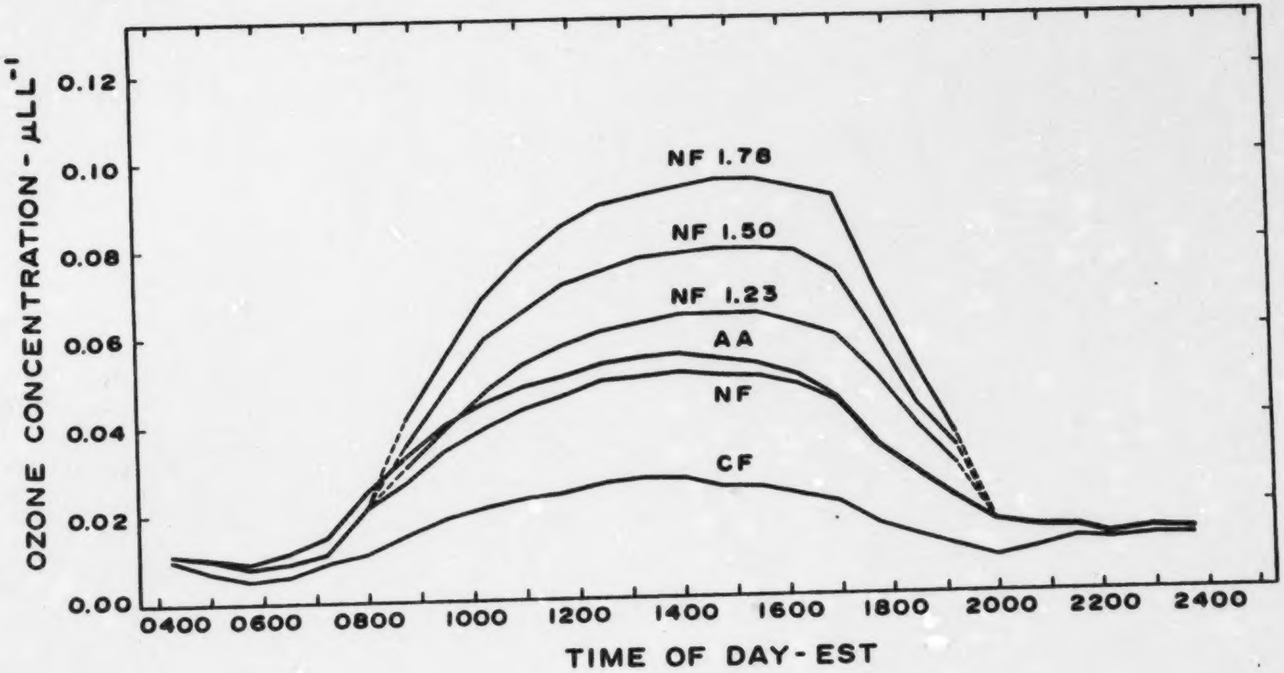

Figure 4.1.1.2. Mean seasonal hourly averaged O_3 concentrations from 28 June - 30 October 1985 at Raleigh, NC.

stress occurred. Four of these were relieved by irrigation (Table 4.1.1.3.) and the rest by rainfall.

Yield. In the WW plots, seed cotton yields are progressively lower at O_3 concentrations greater than in the CF treatment (Table 4.1.1.6., Figure 4.1.1.3.). In contrast, yields were not markedly affected by O_3 in the WS plots except in the two highest O_3 treatments. Analysis of variance of the seed cotton yields with soil moisture levels combined indicated a significant effect of O_3 (PR > 0.011), but no significant effect of soil moisture or the O_3 x soil moisture interaction (Table 4.1.1.7.). The lack of a significant effect of soil moisture on yield in the ANOVA may be partly due to the convergence of the dose-response yield data relationships for the soil moisture treatments at approximately the NF x 1.4 O_3 treatment level (Figure 4.1.1.3.) (i.e., the dose-response curves cross). When the data from the two soil moisture treatments were analyzed separately by ANOVA, the O_3 effects were significant in the WW treatments (PR > 0.009), but not in the WS treatments.

Polynomial dose-response models were fit to the yield data for the soil moisture treatments separately and combined (Table 4.1.1.8.). When analyzed by soil moisture treatments separately, only the linear term for O_3 in the WW plots is significant. In the combined model, the linear O_3 and O_3 x soil moisture terms are significant. A test of homogeneity of the data from the soil moisture treatments separately also indicated that the slopes are significantly different. Therefore, it appears that water stress did significantly alter the response of cotton yield to O_3.

Weibull dose-response regression models were also fit to the yield data (Table 4.1.1.9.). Based on examination of the residual plots, the Weibull models for soil moisture levels separately and combined fit reasonably well. A test of homogeneity of the response at each moisture level indicated that the shapes of the curves for the models were not significantly different. This indicates that water stress did not significantly alter the O_3 dose-response relationship when using the curvilinear Weibull relationship. This is not necessarily inconsistent with the results of the polynomial model (significant O_3 x soil moisture interaction) since a linear response is tested in that case.

The number of harvested bolls also appeared to be reduced by O_3 in the WW plots (Table 4.1.1.6.), but the ANOVA indicated this trend was not significant (Table 4.1.1.7.). The percent lint content and seed weight also did not show any significant effects of O_3 or water stress.

Quality. Table 4.1.1.10. summarizes the data on the cotton fiber analyses. Analysis of variance for the chambered plots for both soil moisture levels combined indicated that O_3 treatment significantly affected micronaire readings, color + B (yellowness) and sugar content while soil moisture affected micronaire readings and sugar content (ANOVA not shown). The only significant interaction was on color + B. The O_3 x soil moisture interaction shows no clear pattern.

Table 4.1.1.6. Seed cotton yield, # bolls, % lint and seed weight per 100. All values are the mean of two replicate plots.

TRT	12-hr Mean O_3 Conc (ppm)	Seed Cotton wt (g m^{-1})	Bolls (#m^{-1})	% Lint	Seed wt g 100^{-1}
WW					
CF	0.020	443 (100)[a]	316	43	10.4
NF	0.041	424 (96)	309	41	10.1
NF x 1.2	0.050	355 (80)	265	40	10.4
NF x 1.4	0.060	320 (72)	266	38	10.2
NF x 1.7	0.071	234 (53)	214	37	9.3
AA	0.043	307 (69)	211	40	10.1
WS					
CF	0.023	373 (100)	268	40	10.5
NF	0.040	349 (94)	249	41	11.1
NF x 1.2	0.051	371 (99)	282	40	10.6
NF x 1.4	0.062	339 (91)	273	40	10.2
NF x 1.7	0.074	300 (81)	258	38	10.0
AA	0.045	295 (79)	202	40	10.3

---

[a] Values in parentheses are % of the respective CF values.

Table 4.1.1.7. Analysis of variance for yield and boll number of cotton.[a]

Source	df	Yield		Boll#	
		MS	PR > F	MS	PR > F
Moisture Levels Combined					
Ozone	5	11384	0.011	254	0.113
Moisture	1	467	0.663	24	0.650
Ozone x Moisture	5	3048	0.324	101	0.509
Error[b]	12	2332	--	112	--
Well-Watered					
Ozone	5	12148	0.009	253	0.115
Water-Stressed					
Ozone	5	2284	0.47	103	0.50

[a] Analyses with AA plots included in data. Plot values are means of two 1-m quadrants per plot. Yield was measured in grams of seed cotton per meter of row. Boll number is combined total from all harvests.

[b] Pooled estimate of error was used for all F-tests.

Table 4.1.1.8. Polynomial (linear) regression equations for yield (g of seed cotton m^{-1} of row).[a]

Moisture Levels Combined[b]

$$\text{Yield} = \underset{(44)}{548} - \underset{(860)}{3998}\,O_3 - \underset{(63)}{141}\,M + \underset{(1211)}{2791}\,O_3 \times M$$

Well-Watered

$$\text{Yield} = \underset{(54)}{548} - \underset{(1054)}{3998}\,O_3$$

Water-Stressed[c]

$$\text{Yield} = \underset{(37)}{407} - \underset{(600)}{1207}\,O_3$$

---

[a] Analysis with AA plots deleted from data. Standard errors for estimates are given in parentheses. Ozone = seasonal 12-hr/day mean O_3 concentration in ppm.

[b] M = 0 and 1 in well-watered and water-stressed plots, respectively. M is not significant in this model but was left in since the interaction term is significant.

[c] This model is nonsignificant.

Table 4.1.1.9. Weibull regression equations for yield (g of seed cotton m^{-1} of row).[a]

Moisture Levels Combined[b]

$$\text{Yield} = (\underset{(41)}{414} + \underset{(29)}{13}M) \exp [-(O_3/\underset{(0.023)}{0.103})^{\underset{(1.69)}{2.55}}]$$

Well-Watered

$$\text{Yield} = \underset{(46)}{449} \exp [-(O_3/\underset{(0.009)}{0.081})^{\underset{(1.82)}{3.31}}]$$

Water-Stressed

$$\text{Yield} = 370 \exp [-(O_3/0.112)^{4.07}]$$

---

[a] Analysis with AA plots deleted from data. Standard errors for estimates listed in order (α, M, σ, c); O_3 = seasonal 12 hr-/day O_3 concentration in ppm.

[b] M = 0 and 1 in well-watered and water-stressed plots, respectively.

Table 4.1.1.10. Cotton lint and seed analyses.

TRT	UHM-Length (in.)	1/8 inch Gauge		Micro-naire	Color		Sugar (%)	Fatty Acids in Oil (%)	Oil (%)	NH_3
		Strength	Elong. (%)		RD	+B				
VV										
CF	1.17	28.0	7.6	4.2	79.0	9.3	0.28	0.3	22.3	3.55
NF	1.16	28.0	7.1	4.6	78.8	9.2	0.32	0.3	21.7	3.70
NF x 1.2	1.18	29.5	6.8	4.0	79.0	9.2	0.26	0.4	21.7	3.84
NF x 1.4	1.16	27.5	7.2	3.8	80.2	8.8	0.24	0.4	19.5	4.19
NF x 1.7	1.15	28.5	7.3	3.6	78.2	9.1	0.24	0.5	18.4	4.17
AA	1.13	26.5	7.0	4.2	76.8	8.7	0.24	0.3	22.0	3.34
VS										
CF	1.15	27.5	7.1	4.6	79.0	9.2	0.30	0.3	20.5	4.37
NF	1.16	28.0	7.0	4.6	79.5	8.6	0.40	0.3	21.2	3.97
NF x 1.2	1.19	30.5	6.9	4.3	78.0	9.6	0.31	0.3	20.9	4.33
NF x 1.4	1.12	28.5	6.9	4.5	77.8	9.2	0.24	0.3	20.3	4.39
NF x 1.7	1.15	28.0	7.8	3.7	73.8	8.4	0.26	0.5	19.5	4.54
AA	1.14	27.0	6.7	4.1	76.0	9.1	0.25	0.4	21.6	3.74

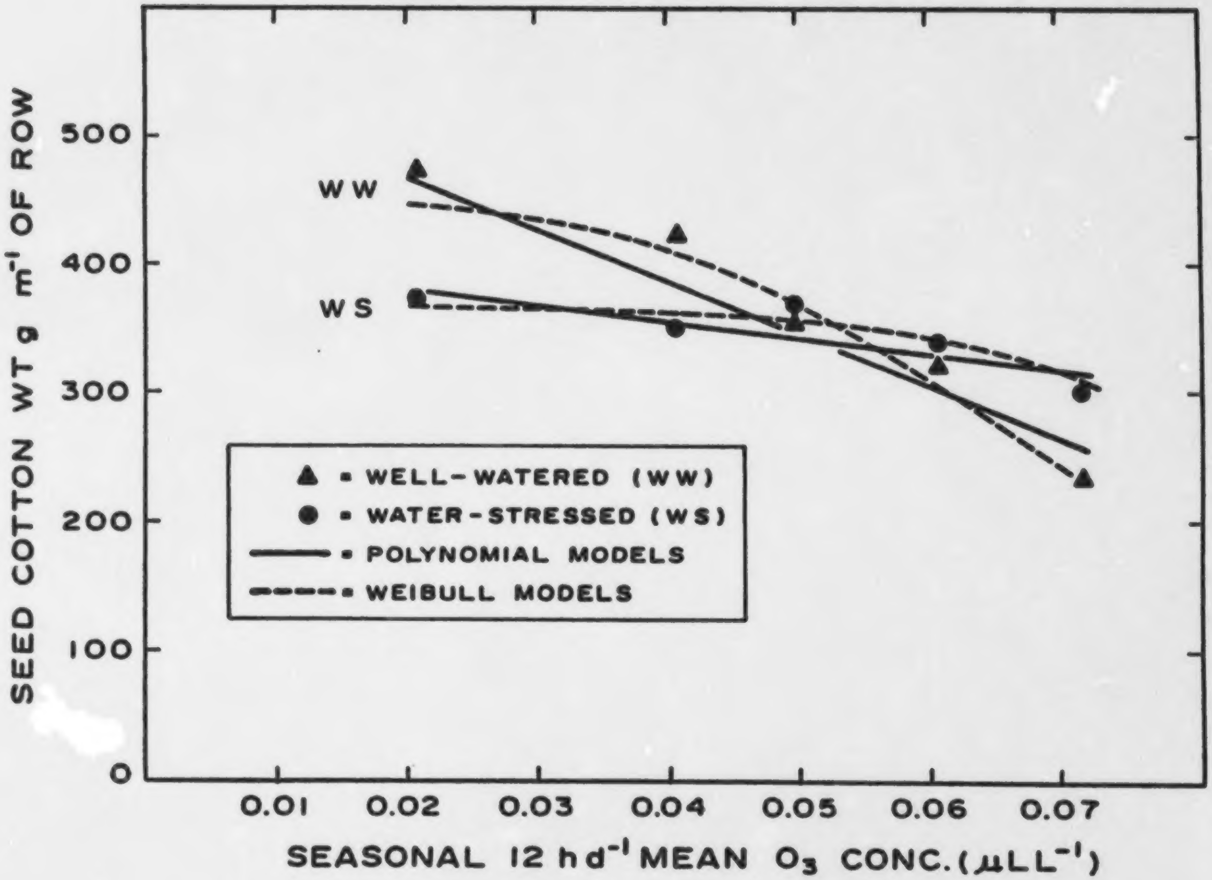

Figure 4.1.1.3. Linear dose-response relationships for cotton yield in 1985 under well-watered and water-stressed conditions.

In the cotton seeds the fatty acid content was significantly affected by O_3 and the NH_3 content by water stress (Table 4.1.1.10.). These are related to the grade of the seeds, although the O_3 and water stress did not significantly affect the grade. The percent oil seemed to be reduced in the NF x 1.7 treatments but this was not significant.

4.1.2. Influence of Soil Moisture on Responses of a Ladino Clover-Tall Fescue Mixture to O_3 (SERCLAP)--A.S. Heagle, Joanne Rebbeck, S.R. Shafer, Udo Blum, W.W. Heck, V.M. Lesser, J.E. Miller, and Diane Camberato

4.1.2.1. Introduction

Tall fescue (*Festuca arundinacea* Schreb.) and ladino clover (*Trifolium repens* L.) are commonly grown together in the southeastern United States. The clover in this mixture provides an economical source of nitrogen and protein for livestock but often disappears after a few years. Ozone is a possible cause for this lack of persistence. Soil moisture is one factor which may change the relationship between O_3 dose and yield response. Our objective was to measure the O_3 dose-yield relationships for a ladino clover-tall fescue mixture grown in the field at two soil moisture levels. This report covers results obtained during the second season of this study. Results obtained during the first season (1984) are in the 1984 NCLAN report (21).

4.1.2.2. Materials and methods

A mixture of ladino clover 'Regal' and tall fescue 'Kentucky 31' seeds was sown in a field of Appling soil on 15 September 1983. Fourteen 3-m diameter plots were chosen in each of two blocks on 2 April 1984 based on the uniformity of stand for both species (28 plots total). Six contiguous quadrats (36 cm x 51 cm each) were marked at the center of each plot on 18 April. Cultural practices were those commonly used for clover-fescue pastures in the Southeast. Detailed materials and methods used in both years and the chronology for important events during 1984 are shown in the 1984 NCLAN Report (21).

The experimental design was two replicates (randomized complete blocks) of six O_3 levels in chambers and one nonchamber (AA) treatment for each of two soil moisture levels. The chamber O_3 treatments included charcoal-filtered air (CF), nonfiltered air (NF), and four NF treatments to which O_3 was added in attempts to obtain multiples of 1.25, 1.50, 1.75 and 2.00 times the amount of ambient O_3 in the NF chambers (NF x 1.25, NF x 1.50, NF x 1.75, and NF x 2.00, respectively). Ozone was added for 12 hr/day (0900 to 2100 hr EDT) when the ambient O_3 concentration exceeded 0.03 ppm from 13 April to 22 October 1985 except during rainy weather and 1-day harvests. The chronology for important events during the 1985 season is shown in Table 4.1.2.1. Irrigation protocols used during 1985 were the same as those described in the 1984 NCLAN annual report. One moisture level which was set to prevent moisture stress [adequate moisture treatment (AM)], called for irrigation when soil matric potential (Ψs) reached -0.4 MPa. The other [low moisture treatment (LM)] called for irrigation when Ψs reached -1.2 MPa. Soil moisture in the top 15 cm of soil was measured gravimetrically in all of the lowest (1.25) and next-to-highest (1.75) proportional O_3 treatment plots on 53 days over the season. Soil moisture was measured gravimetrically in all plots on three dates to establish relationships between the 1.25 and 1.75 proportional treatments and other O_3 treatments. Soil matric potential was estimated using the gravimetric values and soil moisture release curves. The

Table 4.1.2.1. Chronology of activities during the experiment to determine the effects of soil moisture on the response of clover-fescue to O_3 at Raleigh, NC in 1985.

Month	Day	Event
April	5	Root core samples taken for carbohydrate analysis
	9	Pre-exposure harvest in Block I
	10	Pre-exposure harvest in Block II Top panels installed
	12	Bottom panels installed Applied 237g KCl (0-0-60) to each plot
	13	First day of O_3 dispensing
	30	Applied Cygon 2-E (dimethoate) (6.3 cc/l) to all plots
May	13	First harvest after start of exposures in Block I
	14	First harvest after start of exposures in Block II
	21	Applied Cygon 2-E (dimethoate) (6.3 cc/l) to all plots
June	7	Second harvest in plots AA, CF, NF, and 1.25
	11	Applied Cygon to plots harvested June 7
	18	Second harvest in plots 1.50, 1.75, and 2.00
	21	Applied Cygon to plots harvested June 18
July	8	Root core samples taken for carbohydrate analysis
	9	Third harvest in plots AA, CF, NF, and 1.25
	11	Applied Cygon to all plots
	23	Third harvest in plots 1.50, 1.75 and 2.00
	30	Applied Cygon to all plots

Table 4.1.2.1. (cont'd)

Month	Day	Event
August	8	Root core samples taken for carbohydrate analysis
	9	Fourth harvest in plots AA, CF, NF, and 1.25
	13	Applied Cygon to all plots
	22	Fourth harvest in plots 1.50, 1.75, and 2.00
	23	Applied Cygon to all plots
September	6	Fifth harvest in plots AA, CF, NF, and 1.25
	10	Applied Cygon to all plots
	25	Fifth harvest in plots 1.50, 1.75, and 2.00
October	7	Soil samples taken from all plots for nutrient analysis
	22	Last day of O_3 dispensing Root core samples taken for carbohydrate analysis
	23	Final harvest in Block I
	24	Final harvest in Block II

frequency of gravimetric measures varied with the amount of ambient rainfall and irrigation. Soil removed for gravimetric analysis was replaced to decrease the effect of sampling on the rate of soil drying. For each irrigation, 2.5 cm of water was applied over the entire plot area at a rate of approximately 1.2 cm/hr with a solid-cone rain-simulator nozzle.

Plants from each of the six quadrats were harvested before exposures began on 9 April (Block I) or 10 April (Block II) 1985. These data were used in analyses for the 1985 results because the yield was related to O_3 doses in 1984. Protocols for harvests were described in the 1984 NCLAN report. Dates for all 1985 harvests are shown in Table 4.1.2.1. At each harvest, the shoots of clover, fescue and weeds were cut, hand-separated, oven-dried and weighed. Analyses for soluble and insoluble carbohydrates are being performed on leaf and root tissues of both species. Results of these analyses will be reported elsewhere.

Analyses of variance were performed for the moisture levels combined and by individual moisture level for the total dry weight of forage (clover + fescue) produced in 1985. For the individual moisture-level analyses, the significance of blocks and O_3 were determined, while the analysis for moisture levels combined determined the significance of block, O_3, moisture, and O_3 by moisture interaction.

Polynomial dose response models and nonlinear Weibull models were obtained for the combined (adequate plus inadequate moisture plots) and by moisture regime. The response models fit for the combined moisture levels contained an added parameter (M) to account for the direct effects of moisture.

4.1.2.3. Results

Moisture treatments. Periods of low rainfall during April to early May, late May to early June, mid-July, mid-August, most of September and most of October (Table 4.1.2.2.) allowed us to control soil moisture at fairly regular intervals throughout the season by differential irrigation (Table 4.1.2.3.).

Pollutant doses. Dates and hours of suspended O_3 dispensing due to system malfunctions, harvests, rain, and irrigation in 1985 are shown in Table 4.1.2.4. Total dispensing down-time due to all of these causes was 8.5 percent. The mean seasonal 12-hr (0800 to 2000 hr EST) O_3 concentrations in ambient air and for the various chamber treatments for the period 13 April to 22 October are shown in Table 4.1.2.5. For the 12-hr means, the seasonal proportions that resulted in the chambers with O_3 added were 1.27, 1.53, 1.69, and 1.88 times the amount of O_3 in the NF chambers with no O_3 added. The mean 1985 seasonal diurnal fluctuation in O_3 concentrations for ambient air (monitored at a height of 5 m) and for the chamber treatments are shown in Figure 4.1.2.1. Daily 12- (0800-2000 hr EST) and 24-hr O_3 concentrations at a height of 5 m in ambient air from 13 April to 22 October 1985 are shown in Figure 4.1.2.2.

Table 4.1.2.2. Dates, amounts, and pH of rainfall during the experiment to determine the effects of soil moisture on response of clover-fescue to O_3 at Raleigh, NC in 1985.

Month	Day	Rainfall cm[a/]	Rainfall pH
April	13	0.2	4.1
	14	0.2	5.6
	16	0.5	4.3
May	2	1.9	4.7
	10	0.1	4.8
	11	1.1	5.7
	13	0.1	---
	16	1.5	4.3
	17	0.1	4.6
	21	2.7	4.1
	22	0.5	4.1
	23	1.3	4.2
June	5	1.9	4.2
	7	0.4	4.1
	12	1.8	4.3
	17	2.0	4.8
	18	0.5	4.1
	29	1.0	4.0
July	1	3.1	4.6
	2	1.8	4.0
	7	1.4	4.7
	11	1.1	4.1
	13	0.1	4.1
	14	0.1	4.0
	16	0.2	---
	22	0.2	4.0
	23	0.2	3.7
	24	3.8	5.2
	26	0.3	4.5
	28	0.1	4.5
	29	1.1	4.9
	31	1.0	4.0
August	1	1.9	4.0
	17	1.9	4.4
	18	0.6	4.0
	20	0.5	4.2
	21	0.2	4.0
	24	2.6	4.6
	26	1.7	4.7
	29	0.5	4.3

Table 4.1.2.2. (cont'd)

		Rainfall	
Month	Day	cm[a]	pH
September	22	0.7	5.0
	26	0.2	5.7
October	2	0.8	5.0
	3	2.9	5.0
	15	1.1	4.4
	20	1.0	4.9
	21	0.8	4.5
	22	0.2	4.7
	30	0.1	5.4
November	1	0.5	5.5
	2	0.3	4.8
	3	1.5	5.4
	4	3.1	4.9
	12	0.3	5.5
	20	7.0	5.3

[a] Includes all rain events with deposition greater than 0.025 cm.

Table 4.1.2.3. Dates of irrigation in the clover-fescue O_3-water-stress study at Raleigh, NC in 1985.

Dates Irrigated		Soil Moisture Treatment[a] Adequate	Low
April	21	X	
	23		X
	26	X	
	30		X
May	1	X	
	8	X	
	9	X	X
	29	X	
	31		X
June	4	X	
	6		X
	12	X	
	16		X
	24	X	
	26		X
	28[b]	X	
July	16	X	
	19		X
	24	X	
August	12	X	
	15		X
September	6	X	
	9		X
	12	X	
	16		X
	19	X	
October	14	X	
	Total	45.0 cm	27.5 cm

---

[a] Irrigation (2.5 cm) was applied when adequate moisture plots reached a soil matric potential of approximately -0.4 MPa and low moisture plots reached approximately -1.2 MPa as determined gravimetrically. Water was applied by overhead irrigation. The flow rate from each nozzle was measured to determine irrigation duration for each plot.

[b] 5.0 cm of water was applied on this date.

Table 4.1.2.4. Dates and hours of suspended dispensing due to system malfunction, rain, irrigation, and harvest for the clover-fescue O_3-water-stress study at Raleigh, NC in 1985.

Month	Day	Hours of Suspended Dispensing Due to: System Malfunction	Irrigation and Rainfall	Harvest
April	21		2.0	
	23		2.5	
	24		1.0[a/]	
	26		2.5	
	30		3.0	
May	1		2.0	
	3	1.0		
	8		2.5	
	9		4.0	
	13			12.0
	14			12.0
	17	3.0		
	21	5.5		
	24	1.0		
	29		3.0	
	31		3.0	
June	4		2.0	
	6		3.0	
	7			12.0
	12		2.5	
	16		3.0	
	18			12.0
	24		2.5	
	26		2.5	
	28		5.0	
July	8	2.0		
	9			12.0
	11	3.0		
	13	2.5		
	16		2.0	
	19		2.5	
	23			6.0
	24		2.5	
August	9			12.0
	12		0.5	
	15		2.0	
	16	4.0		
	22			12.0

Table 4.1.2.4. (cont'd)

		Hours of Suspended Dispensing Due to:		
Month	Day	System Malfunction	Irrigation and Rainfall	Harvest
September	5			7.0
	6	2.0	2.0	
	9		3.0	
	12		2.0	
	16		4.0	
	18		2.5	
	25			6.0
October	14		2.0	
Total Hours		24.0	71.0	103.0
Seasonal percent of time down[b]		1.0	3.1	4.4

[a] Suspension due to pesticide application.

[b] Seasonal total calculated as 193 days x 12 hours/day = 2316 hours from April 13 to October 22.

Table 4.1.2.5. Seasonal O_3 concentrations for the experiment to measure the effects of soil moisture on response of clover-fescue to O_3 at Raleigh, NC in 1985.[a]

	12-hr/day values (ppm)			1-hr/day values (ppm)		
Treatment	Seasonal Means	Highest	Second Highest	Seasonal Means	Highest	Second Highest
*CF+	0.029	0.054	0.054	0.044	0.077	0.075
*CF-	0.031	0.059	0.055	0.046	0.084	0.073
*NF+	0.047	0.092	0.088	0.062	0.118	0.115
*NF-	0.050	0.099	0.093	0.065	0.117	0.117
NFx1.25+	0.062	0.123	0.122	0.085	0.169	0.162
NFx1.25-	0.062	0.129	0.124	0.084	0.163	0.159
NFx1.50+	0.074	0.154	0.145	0.105	0.217	0.202
NFx1.50-	0.076	0.161	0.156	0.107	0.217	0.208
NFx1.75+	0.082	0.177	0.170	0.119	0.242	0.234
NFx1.75-	0.084	0.186	0.173	0.121	0.246	0.234
NFx2.00+	0.091	0.201	0.191	0.135	0.276	0.264
NFx2.00-	0.092	0.205	0.194	0.140	0.271	0.261
*AA+(field)	0.048	0.086	0.084	0.063	0.112	0.112
*AA-(field)	0.048	0.094	0.086	0.064	0.124	0.113
AA (roof)	0.056	0.103	0.100	0.070	0.134	0.129

[a] Each value is the mean of two sets of readings, except those marked with an asterisk which are a single value; + = adequate soil water; - = water-stressed.

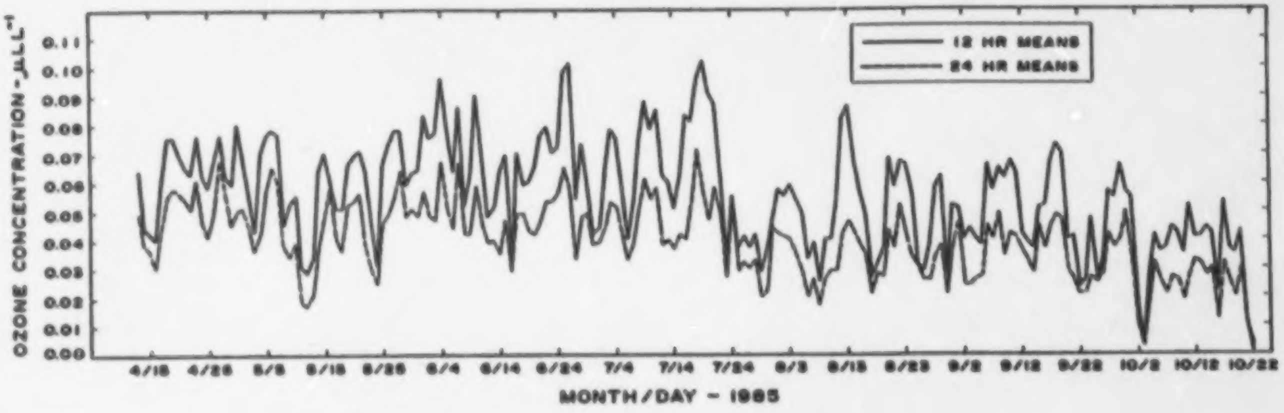

Figure 4.1.2.1. Season mean diurnal fluctuations in O_3 concentrations for the different O_3 treatments from 13 April to 22 October, 1985. The ambient air curve (AA) was derived from samples taken at a height of 5 m (roof values). The curve for AA plots was almost identical to the NF curve.

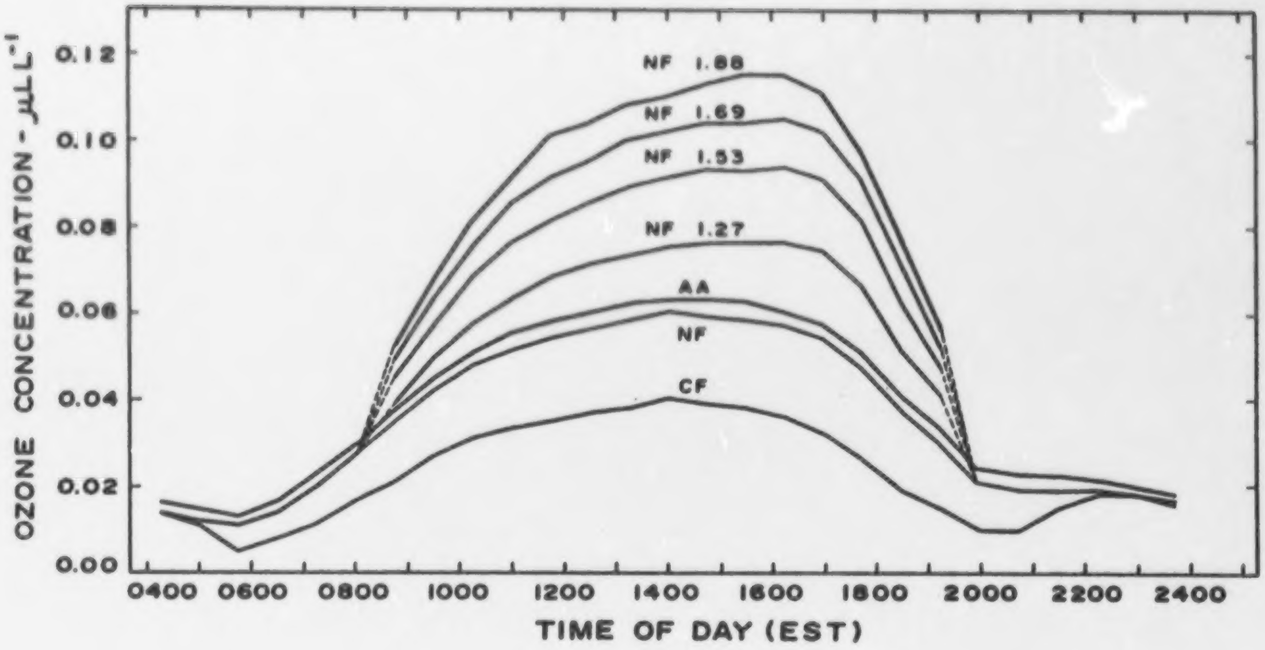

Figure 4.1.2.2. Daily 12- and 24-hr mean O_3 concentrations in ambient air at Raleigh, NC from 13 April to 22 October 1985.

Growth and species composition. Ozone decreased clover growth but increased fescue growth at both moisture levels. The rate of biomass production for each species was directly related to the O_3 level. The effects of O_3 on relative species biomass production increased with exposure time at both soil moisture levels. For example, in the AM treatment, clover and fescue growth rates were not affected much by O_3 for the second and third harvests in 1984. However, at some time between harvests three and four in 1984, a trend for decreased clover and increased fescue production was apparent in the highest O_3 treatments which was not apparent in the lowest O_3 treatment. By the end of 1984, clover growth had mostly ceased in the two highest O_3 treatments. The results for 1984 are shown in Table 4.1.2.6. of the 1984 NCLAN report (21).

Trends established in 1984 continued in 1985. Although a small temporary recovery of clover growth occurred in the high O_3 plots during April and May, growth had mostly ended by mid-June. For the lower O_3 treatments, production of clover biomass essentially ceased by the end of the 1985 season in all but the CF AM treatment. The differences between species biomass production at the lower O_3 levels were greater in the AM plots than in the LM plots indicating that low soil moisture also caused an increase in fescue over clover. The 1985 total production of clover and fescue biomass in the different O_3 treatments at each soil moisture level is shown in Table 4.1.2.6. The clover/fescue biomass ratio changed dramatically over the 2-year period in all O_3 treatments. Before exposures began on 12 April 1984, the range in ratios of clover biomass to fescue biomass between plots was 3.7 to 7.7. At the end of the first season of exposure, the seasonal total clover/fescue biomass ratios ranged from 12.5 in the CF AM treatment to 1.1 in the NF x 2.0 AM treatment (Table 4.1.2.6., 1984 NCLAN Report). By the end of the second season, a ratio of 3.0 occurred for the CF AM treatment but the ratio for all other treatments was between 0.2 and 0.4 (Table 4.1.2.6.). Weeds (mainly crabgrass) increased in all plots. The increase in weed growth was directly related to the O_3 dose in 1984 but this relationship was not as clearcut at O_3 levels above CF in 1985 when crabgrass invaded most plots after clover growth ceased near the end of the season (Table 4.1.2.6.).

The analyses of variance (ANOVA) for the AM plots showed a significant O_3 effect for yield of clover (decreased), of fescue (increased), and for total forage (Tables 4.1.2.6. and 4.1.2.7.). The AOV for the LM plots showed a significant O_3 effect for clover and for total forage (Tables 4.1.2.6. and 4.1.2.7.). The ANOVA for the moisture treatments combined showed significant O_3 x moisture interactions for clover and fescue separately but not for total forage (Table 4.1.2.7.). The interactions were probably caused by yields in the CF and NF plots. For clover, the decrease from the CF to the NF treatment was much greater in the AM plots than in the LM plots. For fescue, there was increased yield from the CF to the NF treatments in the AM plots but the reverse was true in the LM plots. General trends in yield response of the two species to O_3 between the NF to NF x 2.0 treatments were similar at both moisture levels (Table 4.1.2.6.).

Table 4.1.2.6. Total cumulative yield of ladino clover and tall fescue grown in a mixture at two levels of soil moisture and exposed to different levels of O_3 at Raleigh, NC in 1985.

			Total Biomass Measured In 1985 - g/m^2 [a]						Total Biomass Measured In 1984 and 1985 - g/m^2 [a]				
Moisture Treatment	Ozone Treatment	1985 Seasonal Mean 12-hr/day O_3 Conc. - ppm	Clover	Fescue	Total Clover +Fescue	Weeds	Ratio Clover/ Fescue	Two-year Seasonal Mean 12-hr/day O_3 Conc. + ppm[b]	Clover	Fescue	Total Clover +Fescue	Weeds	Ratio Clover/ Fescue
Adequate	CF	0.029	610	203	813	144	3.0	0.027	1649	286	1935	147	5.8
	NF	0.047	281	632	913	236	0.4	0.045	1209	821	2030	242	1.5
	NF x 1.25	0.062	178	480	658	493	0.4	0.062	942	680	1622	519	1.4
	NF x 1.50	0.074	148	513	661	230	0.3	0.072	742	863	1605	248	0.9
	NF x 1.75	0.082	112	539	651	313	0.2	0.081	645	911	1556	354	0.7
	NF x 2.00	0.091	138	467	605	306	0.3	0.089	605	900	1505	366	0.7
	AA	0.048	422	475	897	135	0.9	0.046	1316	575	1891	144	2.3
Low	CF	0.031	250	577	827	54	0.4	0.028	1117	726	1843	56	1.5
	NF	0.050	198	498	696	125	0.4	0.047	1031	646	1677	127	1.6
	NF x 1.25	0.062	198	489	687	342	0.4	0.061	887	683	1570	352	1.3
	NF x 1.50	0.076	83	421	504	120	0.2	0.072	622	740	1362	131	0.8
	NF x 1.75	0.084	134	419	553	143	0.3	0.081	628	736	1364	166	0.9
	NF x 2.00	0.092	78	359	437	240	0.2	0.088	434	698	1132	294	0.6
	AA	0.048	333	560	893	81	0.6	0.046	1233	660	1893	83	1.9

[a] Each value is the mean of 12 36 x 51-cm quadrats (6 in each of 2 plots) from a total of 6 harvests in 1984 and 7 harvests in 1985. (Data from the preexposure harvest in April 1984 were not included for 1984 but data from the April 1985 harvest were included for 1985).

[b] The mean of the 1984 and 1985 values.

Table 4.1.2.7. Mean squares from analyses of variance for yield of clover and fescue exposed to O_3 and moisture stress at Raleigh, NC in 1985.[a]

Source	df	Clover	Fescue	Total Forage[b]
Rep	1	1450	5956	1528
O_3	6	68579**	14173	79915**
O_3 in AM	6	68045**	34821**	33197**
O_3 in LM	6	16969*	12614	56570*
Moisture	1	53861**	29	9852
O_3 * Moisture	6	16435*	33264**	5650
Error	13	4598	7114	5650

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[a] Yields are cumulative dry weights over 7 harvests during 1985; plot values are means of 6 quadrats per plot; * and ** = significant at .05 and .01 probability levels, respectively.

[b] Total forage = clover + fescue dry weights.

Polynomial regression analyses for total forage showed a linear model was adequate in describing plant response to O_3 for both moisture levels (Table 4.1.2.8.). The Weibull models suggest a plateau at the lower O_3 levels in the AM plots but not in the LM plots (Table 4.1.2.8.). However, there were no significant differences in slopes between the LM and AM data for either model. The polynomial regression analyses for moisture levels combined showed an adequate fit with a linear O_3 term and a moisture dummy variable (M) (Table 4.1.2.9.). Neither the O_3 x moisture interaction or higher order terms were significant. The combined Weibull model also contains the M variable and shows a plateau effect at the lower O_3 levels (Table 4.1.2.9.). In-depth regression analyses are planned to obtain polynomial and Weibull models for clover and fescue separately. These will include analyses for separate and combined moisture levels and for 1984 and 1985 data separately and combined.

Table 4.1.2.8. Polynomial and Weibull regression equations by moisture level for total yield of clover-fescue forage exposed to O_3 at Raleigh, NC in 1985.[a]

Polynomial Models	Weibull Models
Adequate moisture	Adequate moisture
$\hat{y} = 996 - 4361\,x$	$\hat{y} = 881 \exp\left[-\left(\frac{x}{0.135}\right)^{2.23}\right]$
(92, 1368)	(149, 0.053, 2.52)
Low moisture	Low moisture
$\hat{y} = 1028 - 6768\,x$	$\hat{y} = 913.9 \exp\left[-\left(\frac{x}{0.111}\right)^{1.79}\right]$
(56, 825)	(148.4, 0.009, 0.99)

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[a] Standard errors for estimates given in parenthesis in order: (α, σ, c); $x = O_3$ concentration (seasonal 12-hr/day mean) in ppm; $\hat{y}$ = estimated yield in g m^{-2}.

Table 4.1.2.9. Regression equations for total weight (g m^{-2}) of clover-fescue exposed to O_3 and moisture stress at Raleigh, NC in 1985.[a]

Polynomial

$$\hat{y} = 972 - 5319\,x + 79\,M$$

(57, 795, 30)

Weibull

$$\hat{y} = (818 + 110\,M)\exp\left[-\left(\frac{x}{0.122}\right)^{2.18}\right]$$

(92, 47, 0.017, 1.20)

---

[a] Standard errors given in parenthesis below equation. For Weibull, they are listed in order: ($\alpha 1$, $\alpha 2$, σ, c). For moisture level, a dummy variable was coded as: M = 0 (low moisture), M = 1 (adequate moisture); x = O_3 concentration (seasonal 12-hr/day mean) in ppm; y = estimated yield in g m^{-2}.

4.1.3. Influence of Soil Moisture on Responses of Soybean to O_3 (CSRCLAP)--L.W. Kress, P.M. Irving, W. Prepejchal, and H.J. Smith

4.1.3.1. Introduction

The influence of water deficits on plant growth and development is one of the most commonly studied aspects of plant physiology. Processes such as transpiration, photosynthesis, and enzyme activity are known to be affected by water stress and O_3 alike. It is generally believed that plants subjected to water stress are less sensitive to O_3. The objective of this study is to determine the influence of drought stress (applied during pod fill) on the O_3 sensitivity of field-grown soybeans. In addition, an examination of various physiological processes may help interpret yield results from this study and aid in understanding mechanisms associated with both O_3 and drought stress.

4.1.3.2. Materials and Methods

Utilizing specially designed manually operated movable rain exclusion covers, a 5 O_3 x 2 H_2O x 2 replication (plus open plots, wet and dry) study was completed with 'Corsoy-79' soybean. Many of the important events concerning the experiment are listed in Table 4.1.3.1. Proportional O_3 additions were performed whenever ambient O_3 was above 0.03 ppm during a 0700-1900 CST window from 23 June to 17 September, 1985 (some of the elevated O_3 treatment plots and most of the drought-stressed plots reached physiological maturity as early as 6 September). The O_3 treatments were charcoal-filtered (CF), nonfiltered (NF), 1.33 NF, 1.67 NF, 2.0 NF, and nonchambered (AA). Prior to 6 August, all plots were exposed to ambient rainfall (Table 4.1.3.2.). During July, all plots were irrigated twice with 2.54 cm H_2O each time. Rain was excluded from all but the AA (wet) plots beginning on 6 August at the initiation of podfill. The non-stressed (wet) plots were irrigated six times with 2.54 cm H_2O each time in August and September (Table 4.1.3.2.). Ambient rainfall for May-September was 78 percent (33.5 cm) of normal (43.2 cm). The non-stressed plots received 127 percent (53.8 cm) and the stressed plots received 65 percent (28.0 cm) of normal. All plots were sprayed twice (August 10 and 27) with Kelthane for spider mite control. The soybeans were harvested from 25 September to 14 October as pods turned brown and leaves abscised.

The soil for this study is a Morley silt loam (fine, illitic, mesic, Typic Hapludalf), upland timber soil. This soil has a high water-holding capacity and low permeability. Information on soil make-up and moisture release curves is presented in Table 4.1.3.3.

Each plot was sampled for O_3 concentration (Bendix Model 8002 Chemiluminescent) for 2 min out of every 22 min. Instruments were calibrated with a CSI Photocal 3000. The O_3 values were adjusted for sample system O_3 losses (6-25 percent) for each plot. The average length of O_3 addition was less than 10 hours per day, due primarily to low ambient O_3 (Table 4.1.3.4.). There were three days when no O_3 was added.

Table 4.1.3.1. Chronology of activities during the experiment to determine the effects of soil moisture stress on soybean response to O_3 at Argonne, IL.

Month	Day	Event
May	11	Fertilizer applied - (N-P-K) - 64-64-64 kg/ha
	31	Corsoy-79 seed planted - 50-cm row spacing
June	4	Plants emerging
	15	Chamber frames in place
	18	Plots thinned to 17 plants/m
	19	Top plastic panels installed
	21	Bottom panels installed - CF filters in - fans on
	23	Initiate proportional O_3 additions - plants at early 2nd trifoliolate stage
July	24	Flowering initiated - R4 stage
August	6	Begin excluding rainfall from all plots - R5.5-R6 stage (pod 0.5-2.0 cm at one of top four nodes)
	8	Spider mite infestation noted
	10	Kelthane applied (11 ml/3.785 liters) - total of 22.7 liters applied on 24 plots - evidence of mites in all plots except AA - all plots moving into R7 stage (beans beginning to develop)
	22	Independent instrument audit
	26	Tied up chamber soybean plants to reduce lodging
	27	Kelthane applied - 18.9 liters on 24 plots - all plots moving into R9 stage (beans full size)
September	4	Senescence beginning in dry plots with elevated O_3
	6-29	Plots in R10 stage (physiological maturity) - generally the dry before the wet, and the high O_3 before the low O_3, and the chambered before the open
	17	Last O_3 addition day
September October	24- 14	Harvest the two center rows (4 m) of each plot as pods turn brown and leaves abscise

Table 4.1.3.2. Dates and amounts of rainfall and irrigation during the experiment to determine the effects of moisture stress on soybean response to O_3 at Argonne, IL.

Month	Day	Rainfall/Irrigation
May	5	0.56 cm rainfall
	7	0.15 " "
	11	0.13 " "
	13	0.08 " "
	14	1.42 " "
	15	0.08 " "
	16	1.47 " "
	20	0.76 " "
	27	2.03 " "
	30	0.05 " "
	31	(Plant soybean seed)
June	2	0.08 cm rainfall
	10	1.22 " "
	14	2.26 " "
	15	0.33 " "
	21	0.28 " "
	23	0.43 " " (O_3 exposures initiated)
	27	0.36 " "
July	2	0.79 cm rainfall
	4	0.66 " "
	8	2.54 " "
	9	1.98 " "
	13	0.15 " "
	14	0.41 " "
	23	2.54 " irrigation
	25	1.78 " rainfall
	30	5.46 " "
	31	0.05 " "
August	4	0.71 cm rainfall
	6	(Rainfall being excluded from all plots, except nonchambered "wet", until harvest)
	12	1.22 cm rainfall
	13	0.08 " "
	13 + 14	2.54 " irrigation on "wet" plots
	14	1.78 " rainfall
	22	2.54 " irrigation on "wet" plots
	24	0.03 " rainfall
	29	1.52 " " - 2.54 cm irrigation on "wet" plots

Table 4.1.3.2. Continued

Month	Day	Rainfall/Irrigation
September	1	2.54 cm irrigation on "vet plots"
	6	0.91 cm rainfall - 2.54 cm irrigation on "vet plots
	8	2.36 cm rainfall
	11	2.54 cm irrigation on "vet" plots
	17	(O_3 additions terminate)
	20	0.18 cm rainfall
	22	1.83 " "
	23	0.46 " "
	25	0.10 " "
	29	0.56 " "

Table 4.1.3.3. Evaluations of content and moisture capacity of the Morley silt loam soil used for the experiment to determine the effects of soil moisture stress on soybean response to O_3 at Argonne, IL.

Depth[a] (cm)	Sand (%)	Silt (%)	Clay (%)	Percent water at			
				1/3 bar	1 bar	7 bars	15 bars
0-15	27	49	24	26.7	21.7	11.8	10.9
15-30	25	41	34	26.5	22.5	14.5	13.6
30-46	26	32	42	28.3	24.9	18.7	17.0

[a] Each value is the average of three samples.

Table 4.1.3.4. Monthly summary of daily O_3 addition start and stop times, daily exposure length, average O_3 concentration at daily exposure stop time, and number of days for various exposure lengths during 87 days for the experiment to determine the effects of soil moisture stress on soybean response to O_3 at Argonne, IL.

Month	Day	Avg. daily start time	Avg. daily stop time	Avg. daily length (hrs)	Avg. amb. conc. at stop time (ppm)	Number of days exposures were		
						12 hrs	> 10 hrs	< 8 hrs[a]
June	23-30	0841	1954	11.2	0.046	3	7	0
July	1-31	0919	1921	10.0	0.054	6	18	5
August	1-31	1057	1914	8.3	0.034	0	6	10
September	1-17	1115	1903	7.8	0.033	1	5	11

[a] There were no O_3 additions on July 30-31 or September 10 due to low ambient O_3. Exposures were terminated at 1500 on five days due to rain.

On five days exposures were terminated at 1500 due to rain. A total of 1.5 hours of exposure time was lost due to generator malfunction.

Ambient SO_2 was monitored continuously during the experiment with a TECO Model 43 Pulsed Fluorescent SO_2 analyzer. Calibration was accomplished with a CSI 1700 Gas Phase Titration Calibrator and an NBS traceable calibrated bottled SO_2 source.

Foliar injury, spider mite infestation, and senescence were estimated in early September in all plots. The top six leaves of four randomly selected plants (one from each quadrant) were evaluated for percent stipple, percent chlorosis, and percent loss due to chewing insects (intervals of 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 percent). Spider mite infestation was estimated as percent of leaves on lower half or top half of all plants in each quadrant with signs of infestation. Senescence was estimated as percent chlorosis on all leaves of the top half of all plants in each quadrant. Chlorosis was also quantified through measurements of chlorophyll content of leaves at the fourth node from the apex on 5 September.

A surface neutron probe (Troxler model 3411-B) which had been calibrated for the soil in this field study was used to monitor soil moisture levels to a 15-cm depth. Beginning the first week of August, the measurements were made between soybean rows in each chamber and ambient plot on a weekly basis and recorded as percent moisture.

Leaf water potential was estimated with a Scholander Pressure Chamber on leaves of the third or fourth node from the apex after preliminary measurements indicated that water potential at these nodes was most consistent from plant to plant. Measurements were made approximately three times per week beginning on 1 August and usually twice on each measurement day, once in the morning before maximum daily moisture stress, and once in the afternoon, usually during conditions of peak moisture stress.

The plants were sampled four times in August and early September to determine chlorophyll content of the middle leaflet of leaves at the third or fourth node from the apex. The chlorophyll was extracted with ethanol and absorbance was measured spectrophotometrically and converted to chlorophyll content according to Knudson et al. (22). Leaf photosynthesis and stomatal conductance were determined with a LiCor 6000 photosynthesis apparatus which measures carbon dioxide and water vapor exchange. Measurements were made on one plant per plot on four different occasions in August.

The plots were sampled twice during the growing season for measures of root biomass and fungal associations. Soil samples were removed from each plot using an 18-mm diameter corer to a depth of 10 cm. Ten samples per plot were taken 2-4 cm from plant stems during the first sampling (August) and 3-6 cm on the second sampling (10 September). Plot samples were pooled for analysis for each sampling date. Roots were sieved, weighed, stained, and evaluated for vesicular-arbuscular (V-A) mycorrhizal fungi. Root samples were also scored for Pythium when spores from this fungus were observed in soil samples taken during the second collection.

To quantify the net heterotrophic activity of the soil (bacterial, fungal, faunal, and root), soil respiration was determined by measuring carbon dioxide evolution from the soil surface for a 24-hr period, according to the method of Stotzky (23). Soil respiration rates were measured in the experimental plots once each in July and August, and twice in September.

Two randomly selected plants per plot were harvested (from rows used for physiological measurements) on 28 August and 5 September for aboveground biomass determinations. Plants were separated into shoots (leaves and stems) and pods; the two sampling dates were pooled for analysis.

Pods and stems from four 1-meter row sections were harvested from each plot as the leaves senesced and pods turned brown (24 September to 14 October). Seeds were separated by hand, counted, oven dried to < 1 percent moisture content, and weighed. Measurements taken at harvest were numbers of plants/m, number of pods with at least one seed/pod, number of seedless pods/plant, and an evaluation of disease problems per plant (virus, bud blight, physical damage, etc.). Seed weight/m row was adjusted to reflect 14 percent moisture content and converted to kg/ha. The weight of 100 seeds was calculated by dividing seed weight/m by the number of seeds/m and multiplying by 100. Soil samples collected after harvest were sent to the Soil and Plant Analysis Laboratory, University of Wisconsin, for analysis of pH, organic matter, P, and K.

The chambered plot data were analyzed by analysis of variance. The sources of variation were O_3 treatment, H_2O treatment, O_3 x H_2O, block, and residual (error). The analysis was also performed for each H_2O treatment individually. Linear, quadratic, cubic, and Weibull models were developed for the O_3 effect in each H_2O treatment and the combined data.

4.1.3.3. Results

Pollutant concentrations. The daily 1-hr peak and 12-hr mean ambient O_3 concentrations were lower in 1985 than in the past few years, especially for August (Figure 4.1.3.1.). The highest 1-hr O_3 value during soybean podfill was 0.081 ppm, and there were only five days when ambient O_3 was above 0.07 ppm. The highest 1-hr O_3 value during the exposure period was 0.107 ppm on 29 July and the highest 12-hr mean was 0.081 ppm on 18 July.

The seasonal O_3 concentration means (12-hr/day mean) were slightly higher in the dry treatments than the wet, due in part to early senescence (and thus different averaging times) in the dry treatments (Table 4.1.3.5.). The average concentrations for the six O_3 treatments were 0.042 ppm, 0.015 ppm, 0.041 ppm, 0.052 ppm, 0.064 ppm, and 0.078 ppm for the AA, CF, NF, 1.33 NF, 1.67 NF, and 2.0 NF treatments, respectively. The highest and second highest 12-hr and 1-hr values have also been

Table 4.1.3.5. Seasonal mean 12-hr/day and 1-hr/day peak O_3 concentrations and the highest and second highest values of each measure, for each treatment during the 0700-1900 CST daily exposure period for the experiment to determine the effects of soil moisture stress on soybean response to O_3 at Argonne, IL.

Treatment	Treatment Days[b]	12-hr/day Values (ppm)[a]			1-hr/day Peak Values(ppm)[a]		
		Seasonal Mean	Highest	Second Highest	Seasonal Mean	Highest	Second Highest
CF+	93	0.014	0.045	0.043	0.024	0.071	0.067
CF-	78	0.017	0.051	0.047	0.029	0.078	0.071
NF+	88	0.040	0.080	0.076	0.057	0.123	0.099
NF-	81	0.041	0.079	0.074	0.058	0.104	0.100
1.33 NF+	87	0.052	0.101	0.094	0.076	0.137	0.124
1.33 NF-	78	0.053	0.101	0.093	0.077	0.136	0.122
1.67 NF+	87	0.063	0.128	0.117	0.095	0.168	0.167
1.67 NF-	80	0.065	0.125	0.112	0.095	0.171	0.157
2.00 NF+	86	0.078	0.156	0.138	0.118	0.199	0.192
2.00 NF-	79	0.079	0.160	0.142	0.119	0.213	0.199
AA[c]	88	0.042	0.081	0.076	0.059	0.103	0.100

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[a] Mean values are the average of two plots with hourly averages generated from 2-3 2-min readings per hour. Highest and second highest values are for one of the two replicates.

[b] All treatments began on 23 June. The O_3 values were calculated for all days up to the estimated date of physiological maturity, which varied due to O_3 and water-stress treatment.

[c] Values from one open plot.

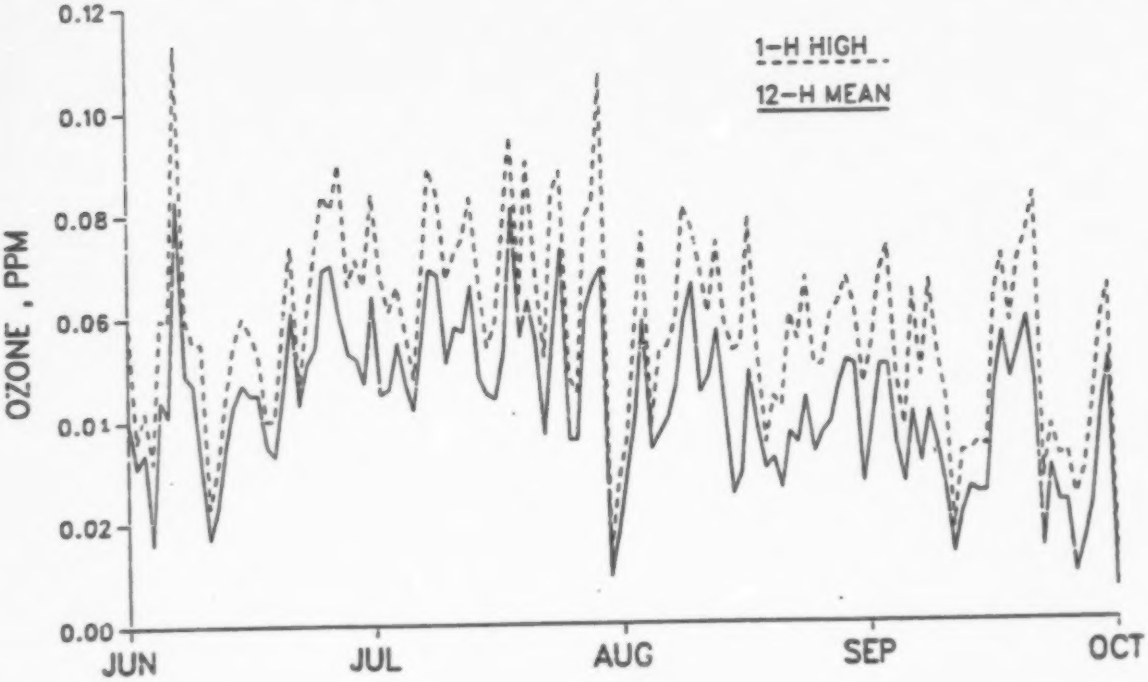

Figure 4.1.3.1. Daily 1-hr peak and 12-hr mean (0700-2100 CST) O_3 concentrations in ambient air measured at a 3-m height during the experiment to determine the effects of soil moisture stress on soybean response to O_3 at Argonne, IL.

provided for each treatment (Table 4.1.3.5.). The mean seasonal hourly average diurnal fluctuations in O_3 concentrations for all treatments are shown in Table 4.1.3.6.

Foliar injury. Foliar injury in the form of pigmented stipple was noted that was not significantly correlated with O_3 treatment, but was significantly ($P = 0.05$) greater in the wet treatments (Table 4.1.3.7.). Injury due to insects, mites, and viruses was noted, but was not significantly correlated with either O_3 or H_2O treatment. Analysis of covariance indicated that none of the injury measures were significant in explaining the treatment variation in seed yield.

Physiology. Differences in soil water content between irrigated and nonirrigated plots were evident in mid-August, soon after rainfall was excluded from plots and irrigation was started in the "wet" plots (Figure 4.1.3.1). In the "dry" plots, soil moisture levels dropped from 25 percent in early August to about 6 percent in mid-September while the wet plots remained above 15 percent moisture throughout the season. Differences in leaf water potential were not observed until late August (Figure 4.1.3.2.). The cool, humid conditions that occurred during August were probably responsible for the lack of an effect of the low soil moisture levels on leaf water potential in the dry plots. By early September, however, leaf water potential in the dry plots was as low as -20 bars while the irrigated plots never had water potentials below -9 bars.

An effect of soil moisture was observed on leaf chlorophyll content only on the last sampling date (5 September) when the dry plots had slightly lower soil moisture levels than the wet plots (Figure 4.1.3.3.). Plants treated with the highest O_3 level in both the wet and dry plots had reduced chlorophyll content compared to plants in all other treatment groups (Figure 4.1.3.4.). This effect was observed as early as 6 August and was of similar magnitude each time it was measured (Figure 4.1.3.5).

Photosynthetic carbon fixation in late August was suppressed by more than 50 percent ($p = 0.0001$) in the dry plots compared to the wet, and was correlated to suppressed stomatal conductance. Although there were no statistically significant effects of O_3 on photosynthetic rate, there appeared to be a trend of reduced stomatal conductance with higher O_3 in the wet plots (Figure 4.1.3.6.). The effect of O_3 on stomatal conductance was also observed in early August before the plots were subjected to two levels of soil moisture (Figure 4.1.3.7.).

Soil moisture level had no effect on the percentage of root tissue infected with either V-A mycorrhizal fungi or Pythium and there was no O_3 effect on net fungal infection. However, the nonfiltered plots had greater percent infection with mycorrhizal fungi and less with Pythium than all the other treatment groups when measured on September 11 (Figure 4.1.3.8.). Soil respiration measurements made before the drought stress was imposed indicated no significant O_3 effect, however, there was a trend of decreasing respiration with increasing O_3 levels. In September, the soil respiration rates in the dry plots were about 60 percent lower than the wet plots and there was no apparent effect from the O_3 treatments.

Table 4.1.3.6. Mean seasonal fluctuations in O_3 concentrations for various treatments in the experiment to determine effects of soil moisture stress on soybean response to O_3 at Argonne, IL.

(ppm)	Seasonal mean per treatment per hour of day[a]					
Time (CST)	AA	CF	NF	1.33 NF	1.67 NF	2.00 NF
0000-0100	0.016	0.016	0.016	0.016	0.016	0.016
0100-0200	0.016	0.016	0.016	0.016	0.016	0.016
0200-0300	0.016	0.016	0.016	0.016	0.016	0.016
0300-0400	0.015	0.015	0.015	0.015	0.015	0.015
0400-0500	0.014	0.014	0.014	0.014	0.014	0.014
0500-0600	0.013	0.004	0.011	0.011	0.011	0.011
0600-0700	0.014	0.004	0.012	0.012	0.012	0.012
0700-0800	0.017	0.005	0.016	0.018	0.020	0.023
0800-0900	0.023	0.008	0.021	0.026	0.030	0.035
0900-1000	0.032	0.011	0.030	0.037	0.044	0.053
1000-1100	0.039	0.014	0.037	0.047	0.057	0.069
1100-1200	0.045	0.017	0.043	0.055	0.067	0.082
1200-1300	0.049	0.019	0.048	0.062	0.075	0.093
1300-1400	0.052	0.021	0.051	0.066	0.082	0.100
1400-1500	0.054	0.022	0.053	0.070	0.085	0.105
1500-1600	0.054	0.021	0.052	0.069	0.084	0.104
1600-1700	0.051	0.019	0.050	0.067	0.083	0.103
1700-1800	0.047	0.016	0.047	0.063	0.078	0.096
1800-1900	0.040	0.013	0.040	0.053	0.066	0.082
1900-2000	0.030	0.010	0.028	0.028	0.028	0.028
2000-2100	0.024	0.017	0.022	0.022	0.022	0.022
2100-2200	0.020	0.020	0.020	0.020	0.020	0.020
2200-2300	0.018	0.018	0.018	0.018	0.018	0.018
2300-2400	0.017	0.017	0.017	0.017	0.017	0.017

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[a] Each value is the mean of two plots for each of two soil moisture levels from 6/23/85 to 7/28/85 (except AA, which was only one plot). Chamber fans operated from 0500-2130 CST.

Table 4.1.3.7. Injury response, plant number, and insect and virus occurrence on soybean plants exposed to O_3 and drought stress in open-top field chambers, 23 June - 28 September, 1985.

Treatment		% Leaf area with[a]				No. Plants/ Meter	% Virus-affected Plants[b]
Soil Moisture	O_3	Stipple	Chlorosis	Insect Chewing	Mite Infestation		
Wet	AA	1	3	4	0	17	22
	CF	0	9	6	6	17	9
	NF	1	10	9	7	18	12
	1.33 x NF	4	18	7	24	18	12
	1.67 x NF	6	13	6	3	17	10
	2.00 x NF	3	11	6	28	17	17
Dry	AA	1	10	12	0	16	20
	CF	0	11	6	1	16	27
	NF	1	12	9	10	18	9
	1.33 x NF	0	18	5	1	16	13
	1.67 x NF	1	10	8	2	18	21
	2.00 x NF	2	25	5	6	17	27

[a] Stipple, chlorosis, and insect chewing damage were estimated on the top six leaves of one randomly selected plant per quadrant per plot. Mite infestation was estimated subjectively on the top halves of all plants in each quadrant per plot.

[b] Virus-affected plants were identified by prolonged retention of green leaves, pods, and stems, witches brooming of leaves and pod initials, and no or few pods (< 15) on the plant.

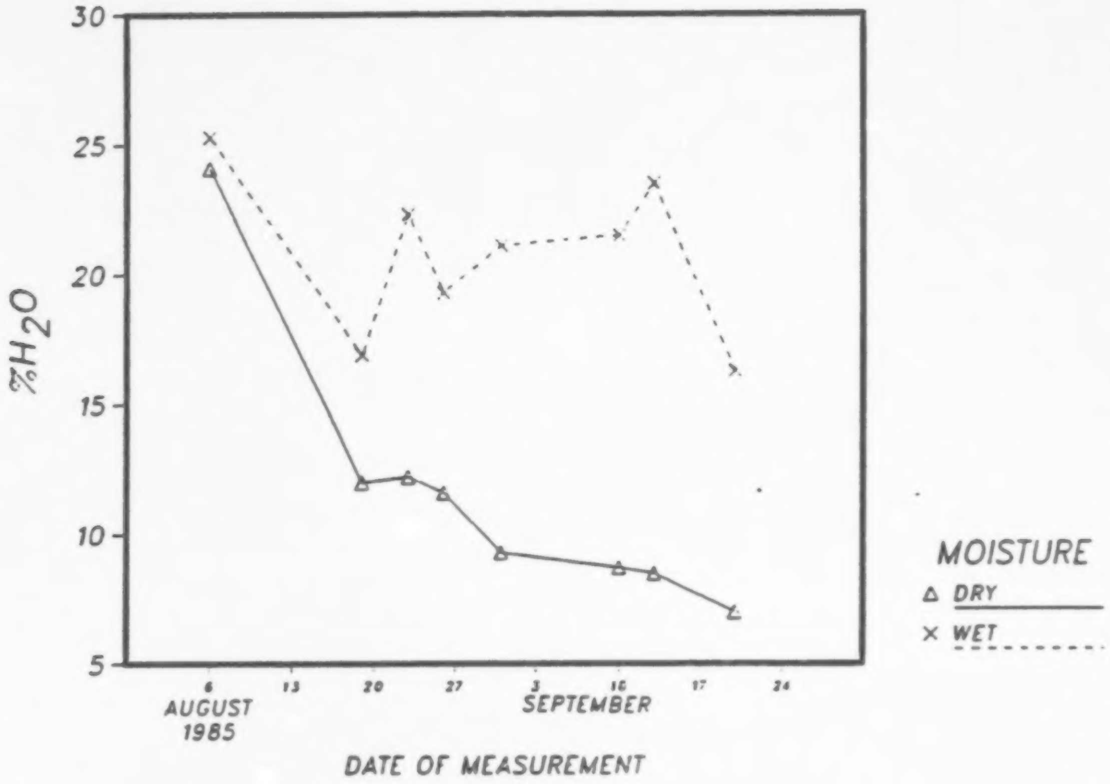

Figure 4.1.3.2. Percent moisture content in the top 15 cm of soil in irrigated (wet) and moisture-stressed (dry) field plots of soybeans.

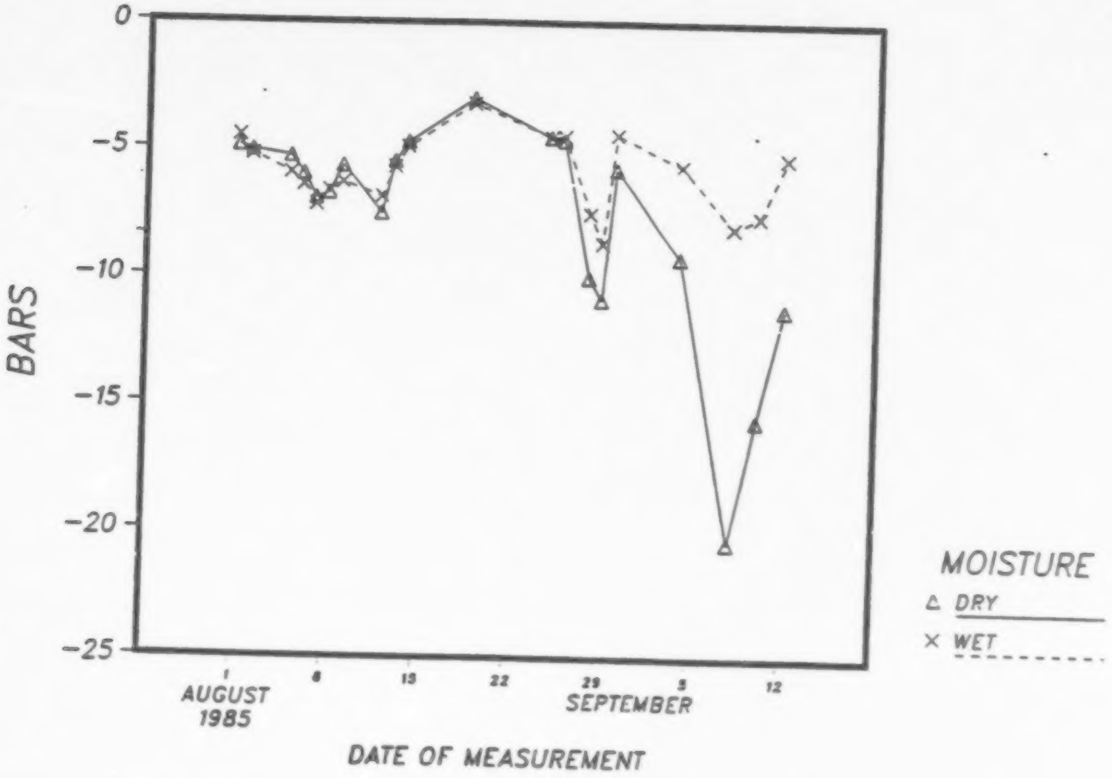

Figure 4.1.3.3. Leaf water potential of soybean plants in field plots receiving two levels (wet or dry) of soil moisture.

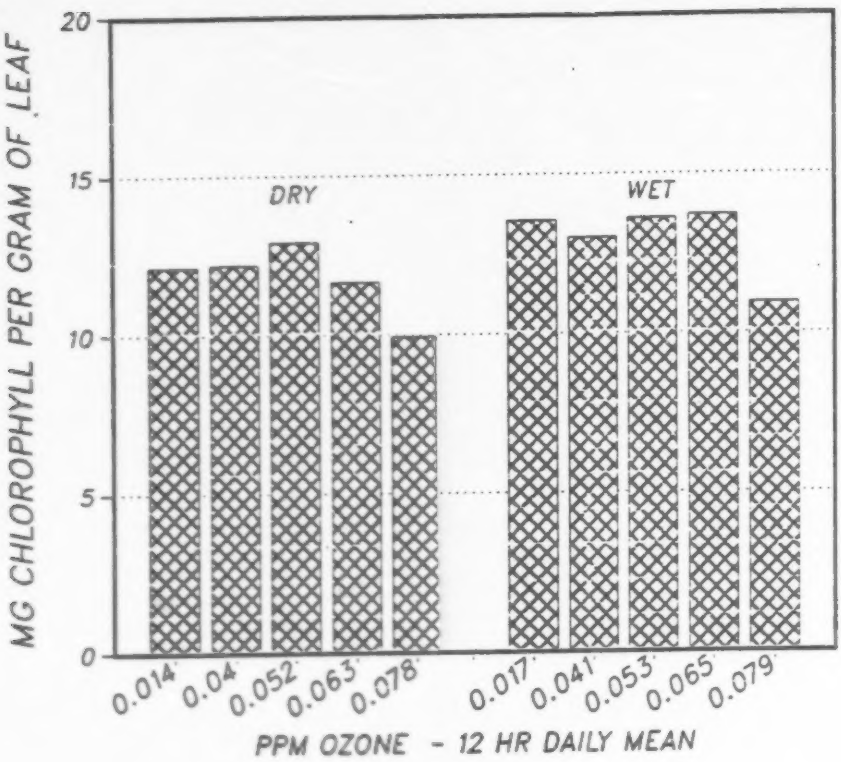

Figure 4.1.3.4. Chlorophyll concentration of middle leaflet at third node from apex of soybean plants sampled on 5 September, as a function of O_3 concertration and soil moisture levels.

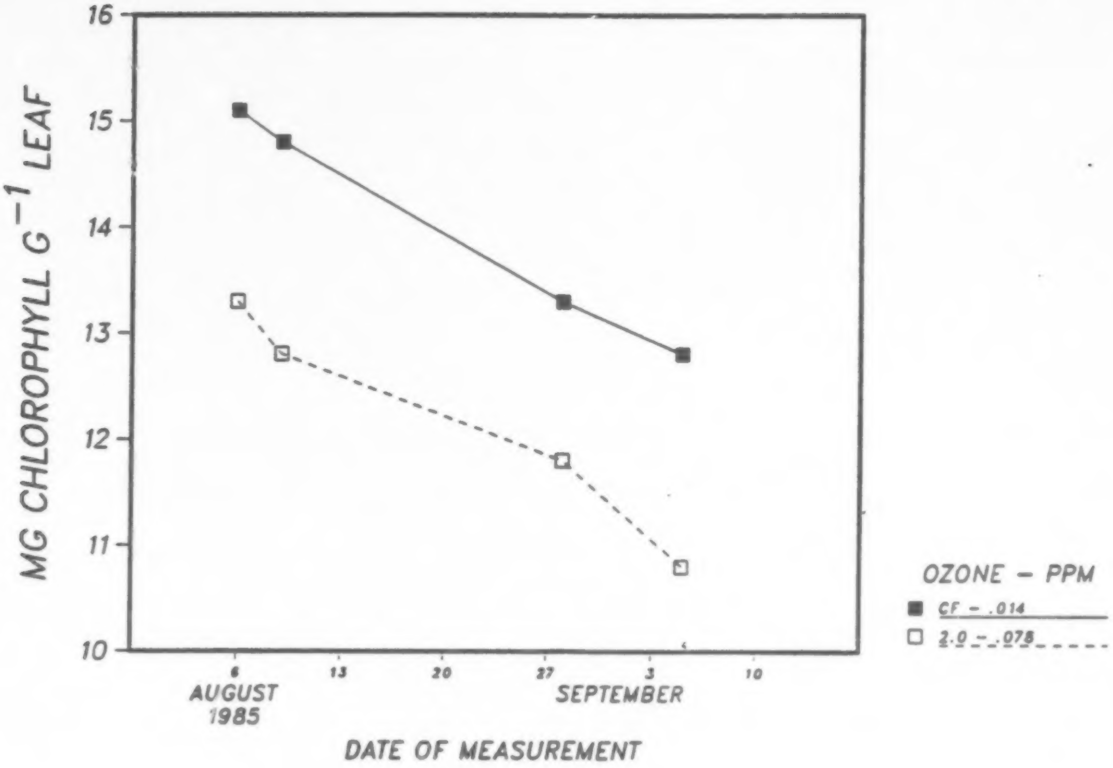

Figure 4.1.3.5. Rate of chlorophyll degradation in soybean leaves exposed to charcoal-filtered air vs O_3 at levels two times greater than ambient.

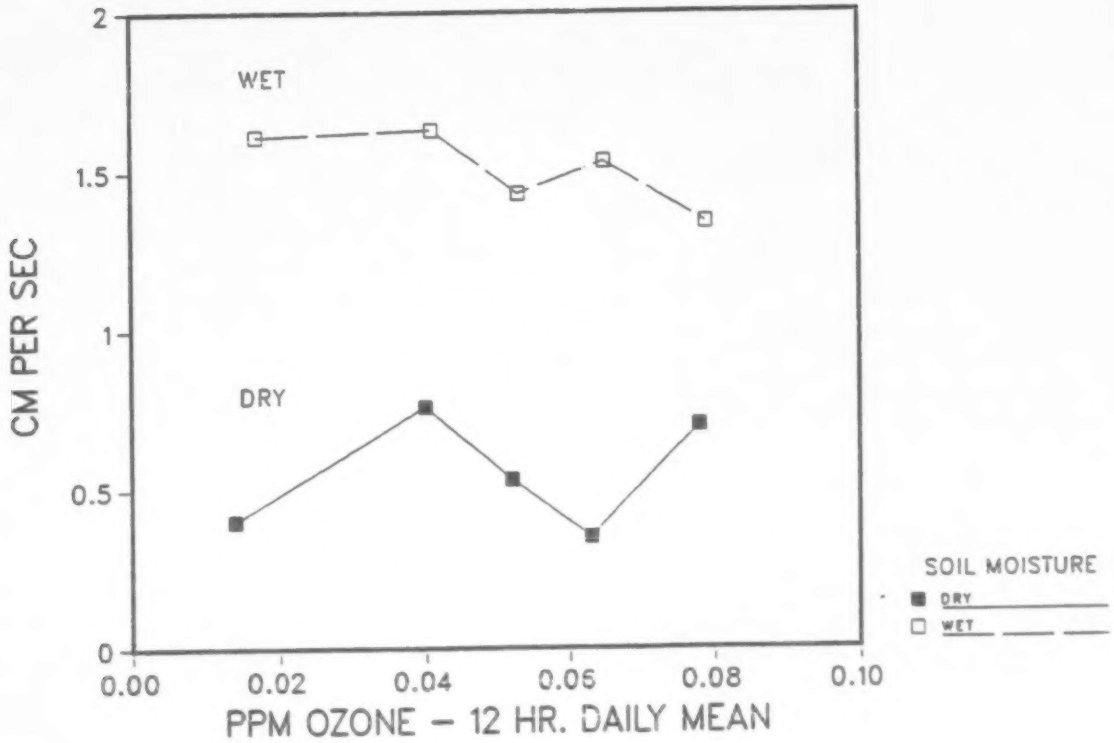

Figure 4.1.3.6. Stomatal conductance of soybean leaves as a function of O_3 concentration and soil moisture level, 28 August.

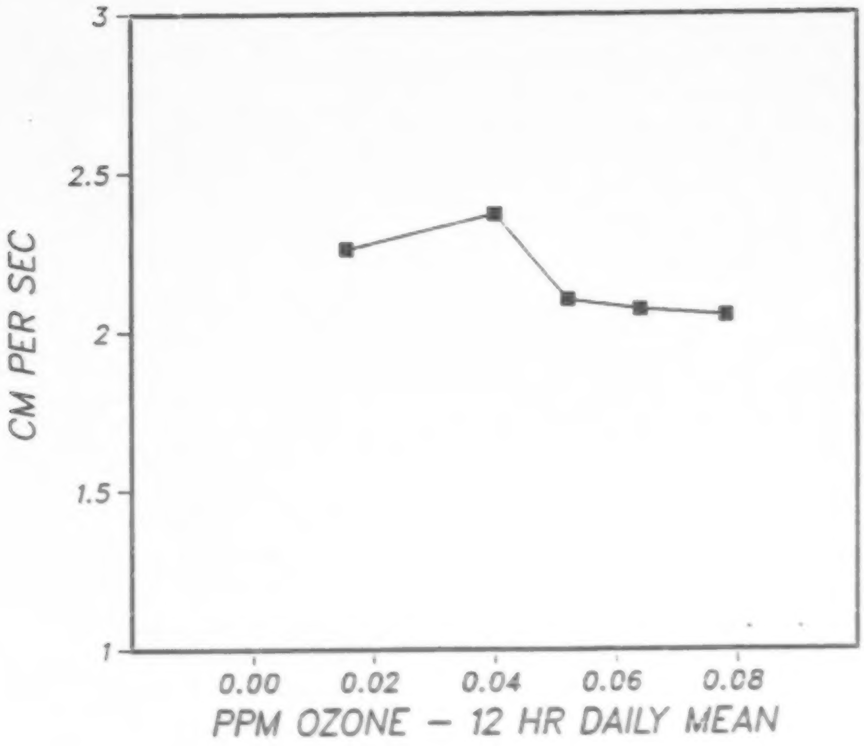

Figure 4.1.3.7. Stomatal conductance of soybean leaves as a function of O_3 concentration, 9 August.

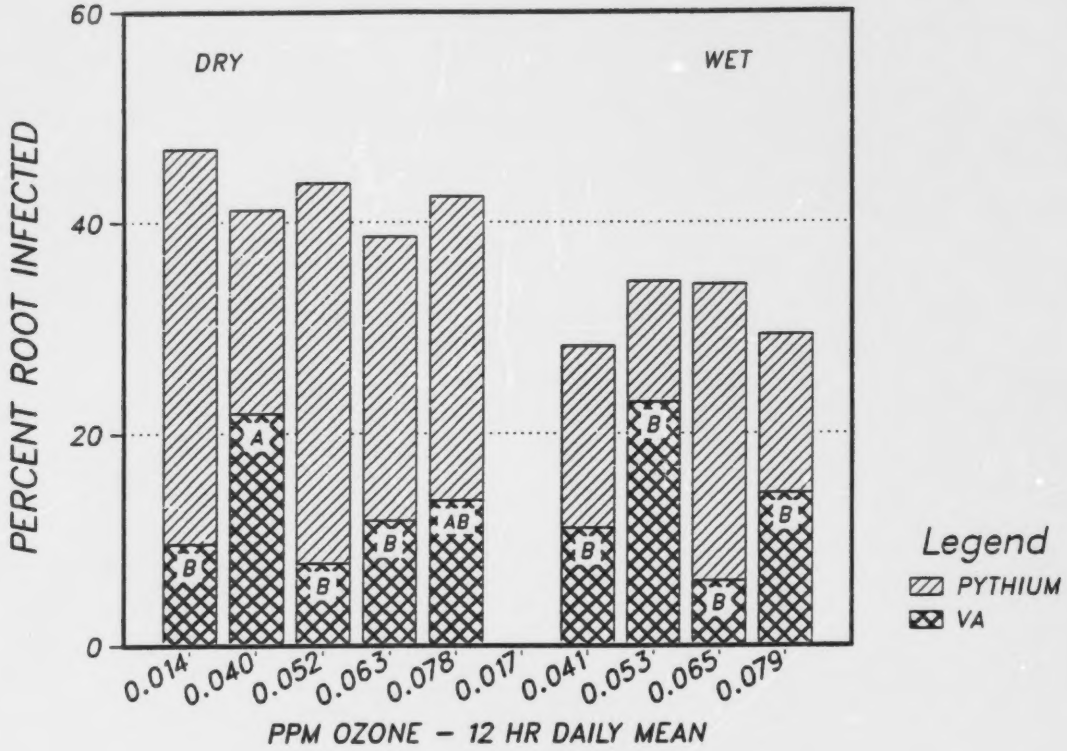

Figure 4.1.3.8. Percent of fine root tissue infected with V-A mycorrhizal and Pythium fungus as a function of O_3 exposure.

The above- and below-ground portions of the soybean plants appeared to respond differently to O_3 depending on soil moisture conditions. Fine root mass of moisture-stressed soybeans was significantly greater ($p = 0.02$) than that of irrigated plants, however, root mass of moisture-stressed plants was negatively affected by O_3 whereas no effect was observed on plants in irrigated plots (Figure 4.1.3.9.). Shoot weight (leaves and stems) was negatively affected by O_3 in the well-watered plots and unaffected by O_3 in the moisture-stressed plots ($p = 0.03$), although overall shoot weight was lower in plants affected by drought conditions compared to irrigated plants (Figure 4.1.3.10.).

Growth and Yield. The analysis of variance of the chambered plot data indicated significant ($p = 0.05$) O_3 treatment effects only for unfilled pods/m. There were significant H_2O stress effects for kg/ha seed yield, weight/100 seeds (100 seed wt), seed number/m, stem weight/m, seed weight/plant, soil organic matter, soil phosphorous, and soil potassium. There was a significant $O_3 \times H_2O$ effect on soil pH and soil phosphorous content. The analysis of variance for the individual H_2O stress treatments indicated no significant O_3 treatment effects for the main yield measures of kg/ha, 100-seed wt, seed number/m, and stem weight/m.

An evaluation of the yield data shows that the drought stress reduced seed yields an average of 23 percent, but not stem weights (Table 4.1.3.8.). The drought stress had a much greater negative effect on the seed yield (also seed number and stem weight) of the CF treatment than on all other treatments. Ozone reduced the yields of well-watered plants up to 17 percent for kg/ha and 30 percent for stem weight compared to the CF plots. For the drought-stressed plants, kg/ha yield in plots exposed to O_3 was greater than in plots treated with CF air for all but the 2.0 NF treatment (6.6 percent reduction) and stem weight was greater in all O_3 treatments. Individual seed weights (100-seed wt) were reduced by the O_3 about equally in wet and dry treatments, but in the dry treatments seed number was increased in all treatments compared to CF. In the wet treatments, the reductions in individual seed weight accounted for about 75 percent of the kg/ha yield reductions. In the dry treatments, the reductions in individual seed weight were about the same as in the wet treatments, but increases in seed number (compared to CF) counteracted the seed weight reductions.

None of the regression models (linear, quadratic, cubic, or Weibull) provide a significant fit for the 12-hr mean O_3 effect using either the combined data set or each H_2O treatment individually. The parameters for the Weibull models are shown in Table 4.1.3.9. The models were generated without including the AA plots because of the obvious chamber effect (Table 4.1.3.8.). Another set of models was also generated without using the CF plots because of the extreme effect of drought stress on the yield of the CF plots.

Weibull models were also produced using the 7-hr seasonal mean to allow comparison with earlier experiments using Corsoy-79 soybeans. The percent yield reductions predicted by the models generated using data from the various experiments are shown in Table 4.1.3.10.

Table 4.1.3.8. Growth and yield responses of soybeans exposed to O_3 and drought stress in open-top field chambers, 23 June - 28 September, 1985.

Treatment H_2O	Treatment O_3	O_3 Concentration (ppm)	Seed Weight (Kg/ha)	Drought-Induced Seed Yield Reduction (%)	100-seed wt (g)	Seed (#/m)	Stem (wt/m)
Wet	AA	0.042	4464		14.9	1304	92
	CF	0.014	3664		14.9	1068	85
	NF	0.040	3391		14.4	1029	59
	1.33 x NF	0.052	3509		14.1	1072	67
	1.67 x NF	0.063	3377		13.9	1062	72
	2.0 x NF	0.078	3029		12.9	1024	59
Dry	AA	0.042	3899	13	13.9	1222	101
	CF	0.017	2450	33	13.1	813	62
	NF	0.041	2758	19	12.6	956	73
	1.33 x NF	0.053	2613	26	12.4	910	71
	1.67 x NF	0.065	2590	23	13.1	867	70
	2.0 x NF	0.079	2283	25	11.5	862	63

Table 4.1.3.9. Weibull model parameters for the effect of O_3 treatment (12-hr mean) on seed yield (kg/ha) of Corsoy-79 Soybean for each H_2O treatment.

Parameter	Delete AA Treatment[a]		Delete AA and CF Treatments[b]	
	Non-stressed	Stressed	Non-stressed	Stressed
Alpha	3564 (291)	2603 (86)	3454 (356)	2780 (313)
Sigma	0.113 (0.092)	0.084 (0.007)	0.099 (0.091)	0.116 (0.063)
C	4.675 (9.502)	30.737 (44.813)	8.520 (33.768)	4.160 (6.617)
R^2 [c]	0.79	0.83	0.87	> 1.00

[a] AA treatment not used in regression due to chamber effects.

[b] CF treatment not used in regression due to extreme sensitivity of CF-plot plants to drought stress.

[c] R^2 = Weibull model SS/O_3 SS from ANOVA. An $R^2 > 1.00$ can occur because the ANOVA does not account for differences in O_3 concentration found in similar treatments, while regression analysis will adjust for these differences.

Table 4.1.3.10. Percent yield reductions predicted from Weibull models generated for Corsoy-79 soybeans using data from four separate experiments.

Experiment	7-hr seasonal mean O_3 (ppm)				
	0.05	0.06	0.07	0.08	0.09
	% yield reduction relative to a 0.025 ppm control				
1985 non-stressed*	2.5	4.7	7.9	12.0	17.3
1985 drought-stressed*	0.0	0.0	0.0	0.1	46.1
1985 drought-stressed[a]* (omit CF)	1.7	3.8	7.3	12.7	20.3
1983 O_3 + SO_2[b]	6.1	10.9	17.4	25.4	34.7
1983 cultivar screen[c]	1.0	3.1	7.7	16.5	30.1
1980[d]	10.4	15.9	21.9	28.3	34.8

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[a] Run model without CF treatment due to extreme sensitivity of CF treatment to drought stress.

[b] Kress, L.W., et al. 1986. Environ. Poll. (Ser. A) 41:105-123.

[c] Kress, L.W., et al. 1984. Nat'l Crop Loss Assess. Network 1983 Ann. Rept., pp. 36-53. (Reference 17)

[d] Kress, L.W. and J.E. Miller. 1983. J. Environ. Qual. 12:276-281. (Reference 8)

* Results of regression analyses were not significant.

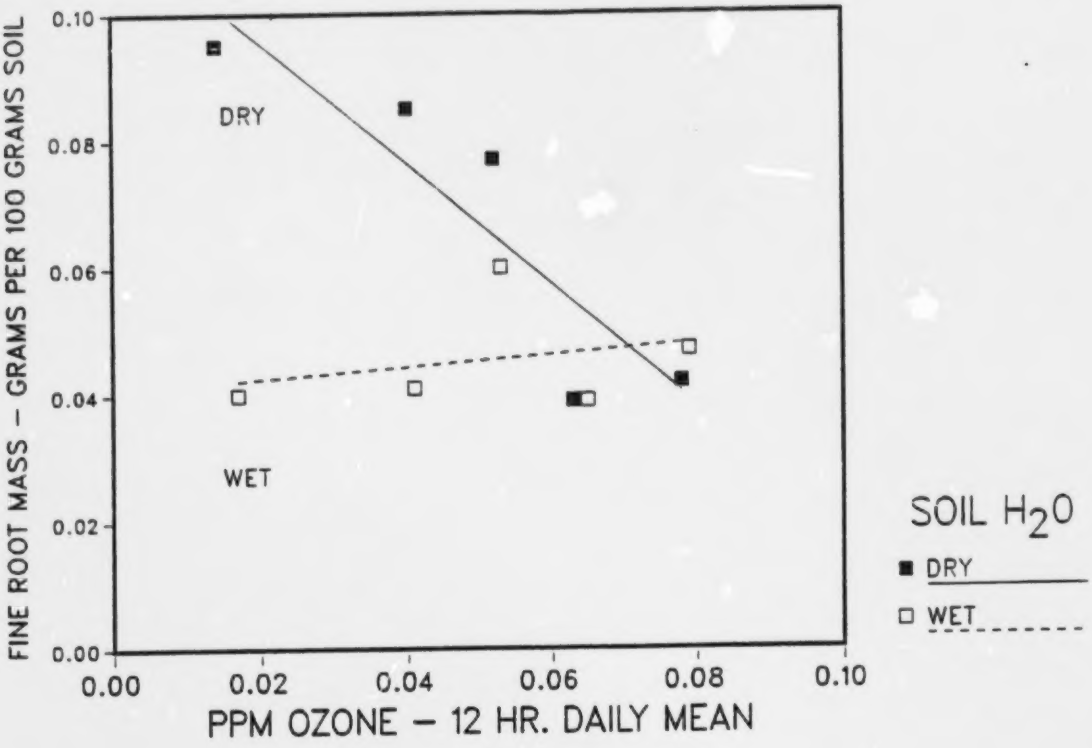

Figure 4.1.3.9. Fine root mass of soybeans exposed to different levels of O_3 and soil moisture.

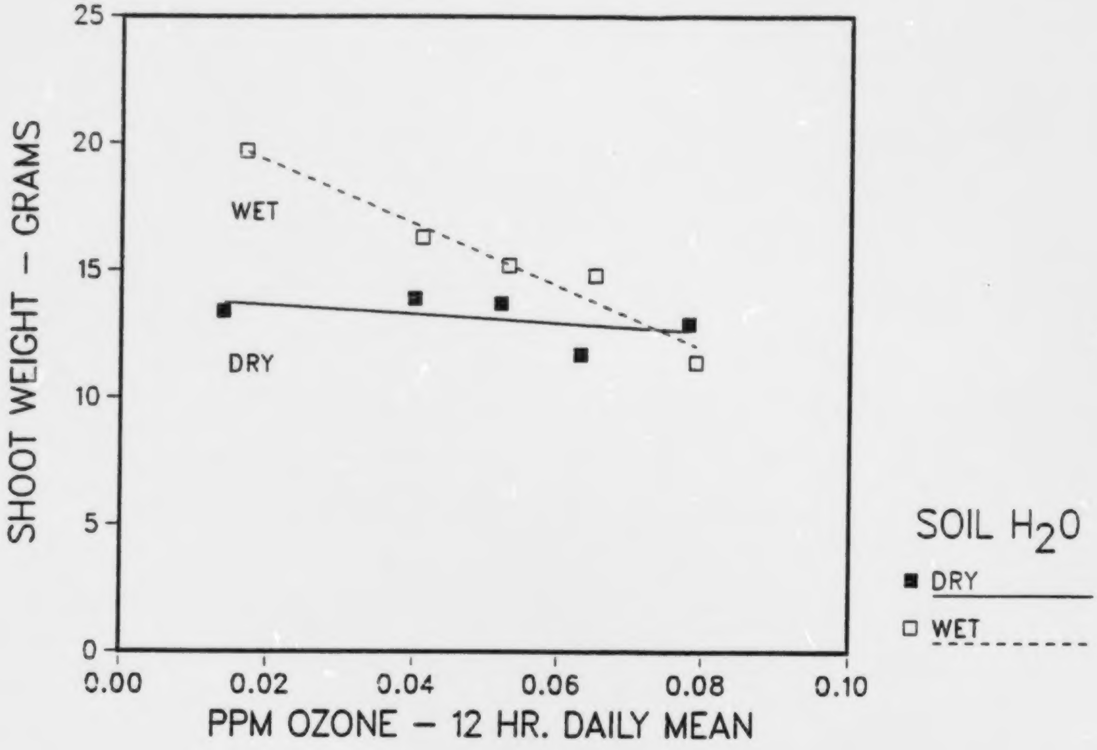

Figure 4.1.3.10. Shoot weight (leaves, stems, and pods) of soybeans exposed to different levels of O_3 and soil moisture.

4.1.3.4. Discussion

Physiology. Our data suggest that moisture stress results in reduced C-fixation in leaves, but increased C-allocation to the fine roots of soybean. The drought-induced stimulation of root growth was apparently suppressed by the O_3 exposure. Conversely, the irrigated plots exhibited greater sensitivity to the O_3 in above-ground vegetative biomass accumulation. Perhaps repair processes due to O_3 exposure result in the utilization of C that would otherwise have been allocated to fine root growth in water-stressed plants while irrigated plants are depleted of shoot biomass C as a result of repair processes.

The effect of moisture stress on stomatal conductance could affect CO_2 uptake and thus photosynthetic rates, but also presumably the uptake of O_3. An effect of O_3 on photosynthetic rates was not observed in this study even though both chlorophyll concentration and stomatal conductance were reduced in the irrigated plots at the high O_3 treatments. Again, repair processes may be responsible for maintaining photosynthetic rates in these plots. There were no apparent direct or indirect effects of O_3 on soil microbial activity as indicated by soil respiration and fungal infection of roots. As expected, soil moisture levels had a significant effect on microbial respiration.

Yield. The drought stress had a rather severe effect on yield (primarily seed number) in the CF treatment, with photosynthate apparently being shifted to root development. Those treatments exposed to O_3 (for six weeks before the drought stress was imposed) apparently did not shift their allocation scheme to root growth when moisture stress was initiated and thus did not demonstrate the dramatic drought-induced root growth enhancement exhibited by the CF treatment. By not including the drought-stressed CF treatment in the estimation of model parameters, predictions of yield suppression from O_3 for the stressed plants were similar to those for the non-stressed plants. It is interesting to note that (when comparing predictions from Weibull models) well-watered plants in 1985 (exposed for 10 hr/day) were, if anything, less sensitive to O_3 than in previous years when plants were not irrigated and were exposed for only 7 hr per day.

The evaluations made for this study are preliminary. Pest problems may have masked potential O_3 effects. There is an obvious need to repeat this study with greater replication before any firm conclusions can be drawn. The results suggest a complex interaction between water and O_3 stresses which may take many years to define.

4.1.4. Response of Alfalfa to O_3 and Water Stress (SWRCLAP)--P. J. Temple, L. F. Benoit, R. W. Lennox, C. A. Reagan, and O. C. Taylor

4.1.4.1. Introduction

A 2-year study on the effects of O_3 on yield of alfalfa grown under two levels of soil moisture was begun in Shafter in 1984. The experimental protocol used in 1984 was repeated essentially unchanged in 1985. The objectives of this experiment were to determine: 1) the degree to which plant water status modified the O_3 dose-crop loss function for alfalfa; 2) the effects of O_3 and drought stress on crop water use and water use efficiency; 3) the responses of a perennial crop to O_3 doses accumulated over two growing seasons.

4.1.4.2. Materials and Methods

The 1984 alfalfa plots were used again in 1985. Ozone dispensing, sampling, and data acquisition systems were the same as in 1984. Ozone treatments consisted of charcoal-filtered (CF); nonfiltered (NF), NF x 1.3, NF x 1.7, NF x 2.0, and ambient air (AA) plots. The last harvest in 1984 was taken on 17 December, and the pre-exposure harvest was collected 20 March 1985. Panels were placed on chamber frames on 21-22 March and O_3 dispensing was begun on 23 March, 12 hours (0900-2100) daily, whenever ambient O_3 exceeded 0.03 ppm. A chronology of significant events during this experiment is given in Table 4.1.4.1.

Irrigation Treatments. The 122-cm long neutron probe access tubes used in 1984 were replaced by 288-cm access tubes for the 1985 experiment. Neutron probe (Model 3220, Troxler Electronics Lab, Sacramento, CA) measurements were taken at six depths (23, 46, 76, 107, and 168 cm) in water- stressed (WS) plots and at seven depths (same as above + 198 cm) in normally-irrigated (NI) plots. Soil moisture readings were taken in early morning (0600-0900) at weekly intervals, on irrigation days, two or three days post-irrigation (to determine field capacity), and the morning after each harvest. The neutron probe was calibrated twice during the year. Volumetric (kg m^{-3}) neutron probe measurements were taken at depths of 23, 46, and 76 cm from each of the 30 alfalfa plots. On the same day, two soil cores (2 cm x 10 cm) were collected from each of these depths. The soil samples were placed in tared soil cans which were closed immediately and oven-dried at 110°C for 48 h. Gravimetric soil moisture (% oven dry weight loss x bulk density of soil = % moisture by vol.) was regressed against neutron probe readings at the same site and depth to determine slope and intercept of the neutron probe calibration curve.

Differential irrigation treatments were begun on 23 March 1985. Normally irrigated plots were watered when soil moisture at 23 cm depth in any CF chamber reached 3.3 cm, indicating 50 percent depletion of available soil moisture at field capacity. Sufficient water was applied to return NI plots to field capacity to a depth of 91 cm, allowing for irrigation efficiency. Water-stressed plots were irrigated when soil moisture in CF plots fell below 2.5 cm (75% depletion of field capacity) and when plants showed symptoms of drought stress (severe wilt; xylem

Table 4.1.4.1. Chronology of significant events during exposure of alfalfa 'WL-514' to O_3 in Shafter, 1985.

Date	Event
3-20	Pre-exposure harvest
3-22	Chamber covers put on; blowers started
3-26	O_3 additions begun
3-27	Rain - 2.5 mm
3-29	Irrigation of NI plots - 18 cm
4-02	Irrigation of WS plots - 10 cm
4-08	Irrigation of NI plots - 10 cm
4-23	Harvest #1
4-25	Irrigation: NI - 10 cm; WS-10 cm
4-26	Crown counts
5-15	Irrigation: NI - 6 cm; WS - 10 cm
5-21	Harvest #2
5-28	Irrigation: NI - 15 cm
6-03	Rain - 17 mm
6-07	Irrigation: NI - 10 cm
6-10	Irrigation: WS - 10 cm
6-18	Harvest #3
6-19	Irrigation: NI - 10 cm; WS - 10 cm
6-28	Irrigation: NI - 10 cm
7-04	Calibration of CWSI
7-05	Irrigation: WS - 10 cm
7-10	Harvest #4
7-11	Irrigation: NI - 10 cm

Table 4.1.4.1. (Continued)

Date	Event
7-17	Thuricide sprayed: 583 ml 1^{-1}
7-19	Irrigation: NI - 10 cm
7-22	Irrigation: WS - 10 cm
7-30	Irrigation: NI - 10 cm
8-07	Harvest #5
8-05	QA Audit of air quality instruments
8-09	Irrigation: NI - 8 cm; WS - 10 cm
8-13	Thuricide sprayed 583 ml 1^{-1}; QA site incpection
8-20	Irrigation: NI - 10 cm
8-21	Thuricide sprayed
8-28	Irrigation: NI - 5 cm; WS - 10 cm
9-04	Harvest #6; trace of rain
9-10	Kelthane (1.3 ml 1^{-1}) and Malathion (4 ml 1^{-1}) sprayed
9-11	Rain: 19 mm
9-24	Rain: 9 mm
9-26	Irrigation: NI - 10 cm; WS - 8 cm
10-01	Thuricide sprayed
10-08	Last day of O_3 dispensing
10-09	Harvest #7
10-10	Chambers removed from plots
10-15	Irrigation: NI - 10 cm
10-16	Irrigation: WS - 10 cm
11-19	Post-exposure harvest
11-20	Crowns removed, counted, and weighed

pressure potentials >-1.3 MPa; elevated canopy temperature). Water-stressed plots were irrigated to return them to 75 percent of field capacity in the top 91 cm of soil.

Plant Water Status. Pressure bomb (Model 3000, Soil Moisture Inc., Santa Barbara, CA) readings were taken on stems with 3-4 fully-expanded leaflets between 1300-1500 during the first three harvests. Xylem pressure potentials in excess of -1.3 MPa were used as evidence of water stress in the plants. For the remainder of the growing season, plant water status was determined by infrared heat gun (Model 110, Everest Interscience, Tustin, CA). Readings of canopy temperature and air temperature differentials were taken weekly, in conjunction with neutron probe measurements, at solar noon once canopy cover reached 100 percent (approximately 10 days after start of re-growth). Measurement position was standardized by reference to chamber doors so that the angle (45° from due S) and canopy area measured (center of sample area) were identical in each plot. A sling psychrometer (Weksler Instrument Co., Freeport, NY) was used to measure air temperature and relative humidity 50 cm above canopy level immediately before heat gun measurements in each chamber or plot. Psychrometer readings were used to calibrate air temperature measurements of the infrared heat gun and wet bulb depression was used to calculate vapor pressure deficit (VPD) in each chamber or plot. Data on canopy-air temperature differentials and VPD were used to calculate a Crop Water Stress Index (CWSI). The CWSI was used to compare plant water status in nonstressed alfalfa plots to that in drought-stressed plots. CWSI was calculated by:

$$\mathrm{CWSI} = \frac{T_c - T_a \; - \; \begin{pmatrix}\text{nonstressed} \\ T_c - T_a\end{pmatrix}}{\overset{\text{total stress}}{T_c - T_a} \; + \; \overset{\text{nonstressed}}{\left| T_c - T_a \right|}}$$

where T_c = canopy temperature, T_a = air temperature, and "total stress" (T_c-T_a) = canopy temperature differentials of non-transpiring alfalfa. Since the absolute magnitude of T_c-T_a varies with VPD, a nonstressed alfalfa base line was established by taking a series of heat gun and psychrometer readings from early morning until late afternoon in CF, NF, and AA plots watered to field capacity. Eleven sets of nine readings per plot were taken to compare canopy temperature differentials for a range of VPD in chambered and nonchambered plots. This method of calculating the CWSI is comparable to calculations of water stress using actual vs potential evaporation. The CWSI was used to determine plant water status from June until the final harvest in November.

Crop water used for each harvest period was determined by measuring the depletion of water in the soil profile to a depth of 2 m in each plot plus the amount of irrigation water added to each plot. Water use efficiency (WUE) was defined as yield (grams d.w.)/water used (ha-cm H_2O).

Disease and Pest Control. Thuricide (*Bacillus thuringensis*) was sprayed at 583 ml l^{-1} at 1-week intervals starting in July and continuing through the third week of each regrowth period. Kelthane MF-48% (1.3 ml l^{-1}) and Malathion 50% (4 ml l^{-1}) were sprayed on 10 September on all plots for control of mites, aphids, leaf hoppers, and lepidopteran larvae.

Harvest Procedures. Plants were harvested when in the 1/10 bloom stage and when crown re-sprouts were 1-2 cm long. Harvest procedures were the same as those used in 1984. Following the last harvest in November, alfalfa crowns were dug from the 1-m sample areas in each plot. Crowns were counted, and fresh and oven-dry weights were determined.

Data Analysis. The experiment was designed as a completely randomized factorial experiment with six levels of O_3 (five in open-top chambers plus AA plots) and two levels of soil moisture with unequal replication (six each of AA, CF, NF plots; four each of NF x 1.3, 1.7, 2.0 plots). Yield data were analyzed by analysis of variance and regression. Preliminary analysis of variance indicated no statistically significant position in chamber interactions, so data from individual 0.25 m^2 harvest plots were summed to produce plot yields in g m^{-2}. Plot yields for the seven harvests in which O_3 was dispensed were summed to produce seasonal yields. Individual plot yields were regressed against seasonal 12-hr O_3 means for each plot using linear and non-linear (Weibull) models. Open (AA) plots were not included in the regression analyses.

4.1.4.3. Results and Discussion

Air Quality and Meteorology. Growing conditions were close to average for Shafter in 1985. Mean daily pan evaporation averaged 5.91 mm d^{-1} for April-October, 1985. In 1984, pan evaporation averaged 6.13 mm d^{-1} for the same period, and the 10-year mean is 6.48 mm d^{-1}. Ambient O_3 was lower in 1985 than in 1984. The 12-hr mean O_3 concentrations averaged between 0.037 ppm and 0.049 ppm for each harvest interval (Table 4.1.4.2.). Seasonal (April-October) O_3 12-hr mean was 0.042 ppm, compared with 0.049 ppm in 1984. Only two hours above 0.10 ppm were recorded in 1985, and 99.5% of all hourly means were below 0.08 ppm (Table 4.1.4.3.). Fluctuations in mean daily ambient O_3 are shown in Figure 4.1.4.1. The 12- and 24-hr mean O_3 concentrations for each treatment for each harvest period are given in Table 4.1.4.2. Frequency distributions of these observations are given in Table 4.1.4.3.

Physiological Responses. Foliar injury symptoms in NI plots were observed in O_3-added exposures 2 to 3 days after start of O_3 additions, or about 6 days after harvest. Upper leaflet surfaces showed a dull, water-soaked appearance, followed by interveinal chlorosis. Progressive symptom development included necrotic stipple and bronzing, followed by premature senescence. Symptoms in NF x 2.0 chambers began 1 to 2 days before those in other O_3-added treatments. Symptom development in O_3-added WS treatments was delayed from 1 to 4 days, in comparison with NI chambers. This delay in symptom expression in WS chambers varied with timing of previous irrigation in relation to start of O_3 additions. The more drought-stressed the plot, the greater the delay in symptom expression

Table 4.1.4.2. The 12- and 24-hr mean O_3 concentrations for O_3 treatments[b/] at Shafter, CA, 1985 (all data in ppm).

Harvest Date	No. Hrs. d^{-1}	Treatment[a/]					
		CF	NF	NF x 1.3	NF x 1.7	NF x 2.0	AA
4/23	12	0.010	0.033	0.056	0.071	0.086	0.037
	24	0.007	0.020	0.031	0.038	0.046	0.022
5/21	12	0.010	0.036	0.061	0.076	0.092	0.039
	24	0.008	0.022	0.035	0.042	0.050	0.025
6/18	12	0.010	0.037	0.066	0.083	0.100	0.041
	24	0.007	0.022	0.037	0.046	0.055	0.025
7/10	12	0.010	0.040	0.064	0.077	0.093	0.044
	24	0.007	0.024	0.036	0.042	0.051	0.026
8/07	12	0.013	0.044	0.069	0.085	0.102	0.049
	24	0.010	0.026	0.039	0.047	0.056	0.030
9/04	12	0.011	0.039	0.067	0.083	0.102	0.045
	24	0.008	0.023	0.037	0.045	0.054	0.026
10/09	12	0.008	0.035	0.058	0.072	0.087	0.039
	24	0.006	0.020	0.032	0.039	0.046	0.022
Season	12	0.010	0.038	0.063	0.078	0.094	0.042
	24	0.007	0.022	0.035	0.043	0.051	0.025

[a/] Treatment abbreviations are explained in the text.

[b/] Ozone concentrations averaged over irrigation levels.

Table 4.1.4.3. Frequency distribution of all hourly O_3 concentrations for each O_3 treatment and ambient air (AA) in Shafter, CA, 26 March to 9 October 1985.

Total Observations	CF 23430	NF 23430	NF x 1.3 18744	NF x 1.7 18744	NF x 2.0 18744	AA 9372
.000<= OB <=.010	16176(69.0%)	8887(37.9%)	6872(36.7%)	6941(37.0%)	6803(36.3%)	3156(33.7%)
.010 < OB <=.020	5923(25.3%)	3460(14.8%)	2355(12.6%)	2247(12.0%)	2277(12.1%)	1424(15.2%)
.020 < OB <=.030	1104(4.7%)	3220(13.7%)	1088(5.8%)	1053(5.6%)	1022(5.5%)	1260(13.4%)
.030 < OB <=.040	157(0.7%)	2960(12.6%)	908(4.8%)	633(3.4%)	588(3.1%)	1168(12.5%)
.040 < OB <=.050	53(0.2%)	2412(10.3%)	1158(6.2%)	638(3.4%)	507(2.7%)	922(9.8%)
.050 < OB <=.060	13(0.1%)	1507(6.4%)	1168(6.2%)	782(4.2%)	423(2.3%)	689(7.4%)
.060 < OB <=.070	3(0.0%)	793(3.4%)	1459(7.8%)	907(4.8%)	578(3.1%)	472(5.0%)
.070 < OB <=.080	0(0.0%)	162(0.7%)	1186(6.3%)	931(5.0%)	651(3.5%)	231(2.5%)
.080 < OB <=.090	0(0.0%)	21(0.1%)	936(5.0%)	906(4.8%)	565(3.0%)	40(0.4%)
.090 < OB <=.100	0(0.0%)	8(0.0%)	878(4.7%)	1043(5.6%)	866(4.6%)	8(0.1%)
.100 < OB <=.110	0(0.0%)	0(0.0%)	497(2.7%)	799(4.3%)	802(4.3%)	2(0.0%)
.110 < OB <=.120	1(0.0%)	0(0.0%)	157(0.8%)	733(3.9%)	777(4.1%)	0(0.0%)
.120 < OB <=.130	0(0.0%)	0(0.0%)	44(0.2%)	575(3.1%)	707(3.8%)	0(0.0%)
.130 < OB <=.140	0(0.0%)	0(0.0%)	25(0.1%)	314(1.7%)	638(3.4%)	0(0.0%)
.140 < OB <=.150	0(0.0%)	0(0.0%)	12(0.1%)	131(0.7%)	492(2.6%)	0(0.0%)
.150 < OB <=.160	0(0.0%)	0(0.0%)	1(0.0%)	65(0.3%)	510(2.7%)	0(0.0%)
.160 < OB <=.170	0(0.0%)	0(0.0%)	0(0.0%)	25(0.1%)	291(1.6%)	0(0.0%)
.170 < OB <=.180	0(0.0%)	0(0.0%)	0(0.0%)	17(0.1%)	109(0.6%)	0(0.0%)
.180 < OB <=.190	0(0.0%)	0(0.0%)	0(0.0%)	2(0.0%)	73(0.4%)	0(0.0%)
.190 < OB <=.200	0(0.0%)	0(0.0%)	0(0.0%)	1(0.0%)	34(0.2%)	0(0.0%)
OB >.200	0(0.0%)	0(0.0%)	0(0.0%)	1(0.0%)	31(0.2%)	0(0.0%)

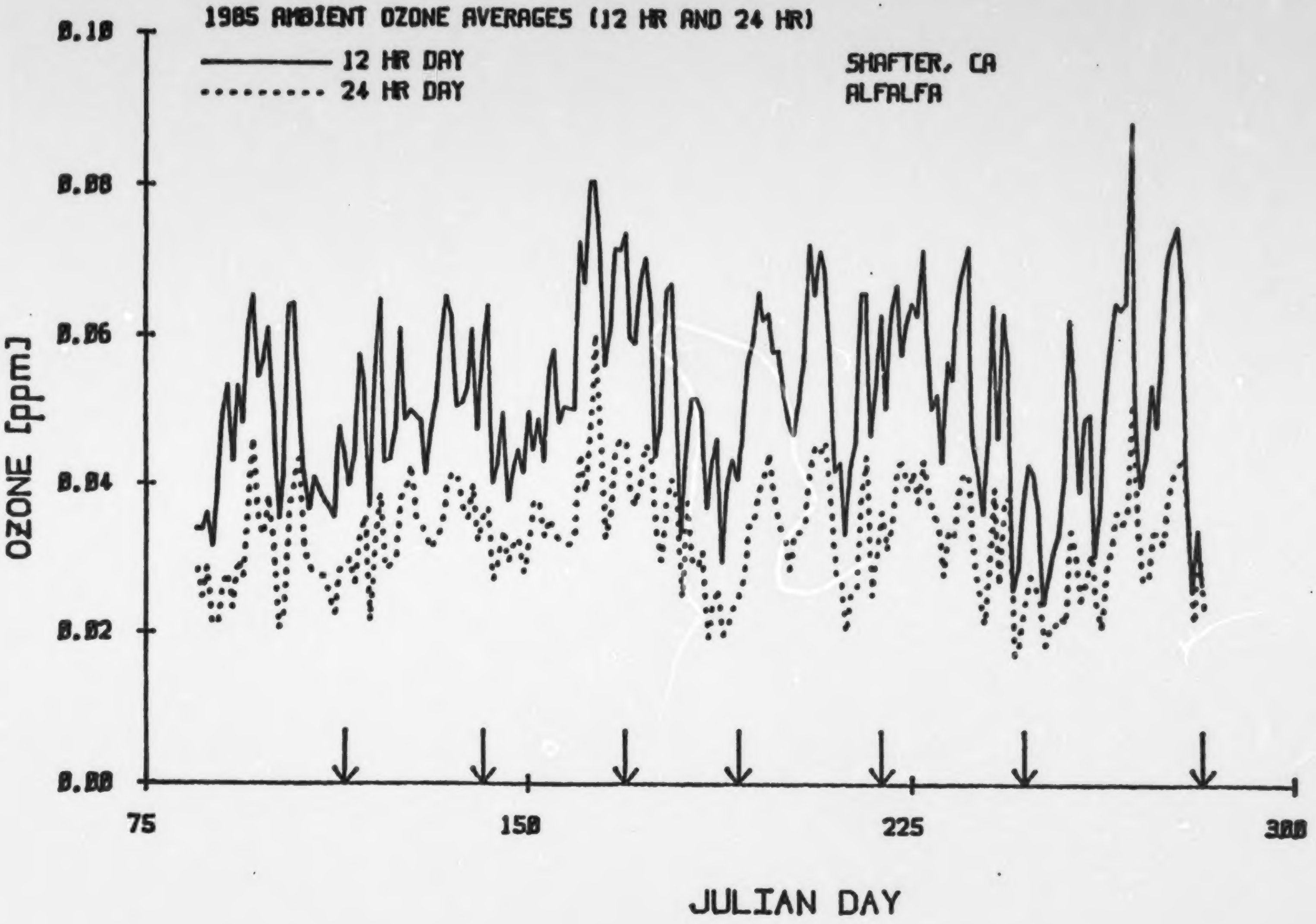

Figure 4.1.4.1. Daily mean 12- and 24-hr ambient O_3 concentrations in Shafer, CA 26 March to 9 October 1985.

relative to NI plots. This lag in development of injury symptoms in WS plots may have been due to reduced stomatal conductance, which averaged 20.2 percent lower in WS compared with NI plots. But WS plots also experienced delayed onset of re-growth after harvest, so lags in expression of O_3 symptoms may also have been due to delay in WS plants reaching the physiological stage of foliar development most susceptible to O_3.

Plant water stress was documented in WS plots during each exposure period except the first (3/26-4/22). Stressed plots received either one (Exposures 2, 6, 7) or two (Exposures 3, 4, 5) periods of water stress during a re-growth cycle, depending upon timing of irrigations in relation to harvests. CWSI of NI plots ranged from 0, indicating no water stress, to a maximum of 0.27, recorded 10 days after an irrigation (Table 4.1.4.4.). CWSI of WS plots ranged from a minimum of 0.05 (3 days after an irrigation) to a maximum of 0.91, indicating almost complete cessation of transpiration, 16 days past an irrigation. Periods of severe water stress (CWSI >0.50) in WS plots ranged from 6 to 11 days, depending upon timing of irrigations and evaporative demand.

Crop Water Use. Water use was less in WS plots than in NI plots (Table 4.1.4.5.). Water use increased as evaporative demand increased, but water use did not vary with exposure to O_3. The pattern of water use efficiency (WUE) was different from that of water use (Table 4.1.4.6.). WUE decreased as the growing season progressed and evaporative demand increased. WUE also decreased as exposure to O_3 increased. Seasonal mean WUE was inversely correlated with seasonal 12-hr O_3 concentration for both NI (r = -0.93) and WS plots (r = -0.90). This O_3-related decrease in WUE may have been due to premature senescence and early leaf drop of older leaves of plants exposed to O_3. Leaves which abscissed early would have used water during growth but would not have added to harvest weight because only stems and green leaves were harvested. Thus decreased WUE in O_3-stressed plants may be related to premature leaf senescence.

Yield Response. Treatment yields for the seven harvests during the O_3-dispensing season are given in Table 4.1.4.7. Alfalfa yield increased in NI plots until the third harvest in June, after which yields declined in all harvests except NF in harvest 5 (Figure 4.1.4.2.). Yields in WS plots were stable or increased until June, after which yields declined as in NI plots (Figure 4.1.4.3.). On a seasonal yield basis, yields in WS plots averaged 27.5 percent less than NI plots. In comparison with yields in CF chambers, O_3 reduced alfalfa yields for both NI and WS plots in all harvests, except for NI-NF plots. Seasonal yields of NI plots were reduced 14.9, 24.3 and 24.9 percent in NF x 1.3, 1.7, and 2.0 treatments, respectively. Yields were not reduced in NF compared with CF plots. For WS plots, seasonal yields were reduced 7.2, 13.6 and 18.1 percent in NF x 1.3, 1.7, and 2.0 treatments, respectively. Yields in NF plots were reduced 5.9 percent relative to CF chambers in WS plots.

Yield reductions in WS treatments were relatively greater at ambient O_3 concentrations and relatively lower at higher O_3 concentrations compared with NI plots, confirming a trend observed in 1984. However, analysis of variance of harvest data indicated that the interaction

Table 4.1.4.4. Crop water stress index (CWSI) for normally-irrigated (NI) and water-stressed (WS) alfalfa in Shafter, 1985, as determined by air-canopy temperature differentials. CWSI can range from 0 (no water stress) to 1; (maximum stress = no transpiration). Each point represents a mean of 30 measurements (± 1 s.d.).

Date	CWSI	
	NI	WS
7-03	0.01 ± 0.05	0.68 ± 0.07
7-08	0.24 ± 0.07	0.05 ± 0.04
7-21	0.20 ± 0.09	0.91 ± 0.04
7-25	0.11 ± 0.06	0.20 ± 0.05
7-29	0.18 ± 0.02	0.26 ± 0.07
8-01	0.15 ± 0.01	0.63 ± 0.08
8-19	0.27 ± 0.06	0.37 ± 0.07
8-23	0.08 ± 0.15	0.42 ± 0.06
8-27	-0.03 ± 0.12	0.84 ± 0.08
9-20	-0.03 ± 0.12	0.72 ± 0.08
9-25	0.16 ± 0.11	0.89 ± 0.06
10-05	0.07 ± 0.09	0.36 ± 0.07

Table 4.1.4.5. Total water use (ha . cm) of normally-irrigated (NI) and water-stressed (WS) alfalfa exposed to O_3 in Shafter, CA, 1985, for each exposure period.

Treatment[a/]		Harvest Date						
		4/23	5/21	6/18	7/10	8/07	9/04	10/09
CF	NI	19.25	17.42	23.63	25.30	31.68	28.44	22.81
	WS	16.50	15.85	17.39	21.33	19.49	19.93	12.14
NF	NI	21.14	18.54	22.87	26.52	33.42	29.82	23.83
	WS	16.64	17.11	21.99	21.60	22.79	20.44	14.42
NF x 1.3	NI	21.14	17.30	21.68	26.08	31.50	27.93	23.96
	WS	16.25	17.17	19.88	22.38	22.19	20.12	14.11
NF x 1.7	NI	20.27	19.13	22.61	26.91	31.91	28.98	24.11
	WS	17.26	19.61	19.89	21.84	23.28	20.26	13.92
NF x 2.0	NI	20.60	15.97	22.11	26.52	31.55	29.27	24.55
	WS	15.41	15.83	20.17	21.62	21.76	19.60	13.16
AA	NI	20.48	17.83	25.68	26.65	34.86	30.64	25.14
	WS	17.37	18.40	20.40	23.50	22.29	20.85	15.56

[a/] Treatment abbreviations are explained in the text. Means of 3 CF, NF, AA plots, 2 NF x 1.3, NF x 1.7, NF x 2.0 plots.

Table 4.1.4.6. Mean water use efficiency (g.d.w./ha . cm H_2O) of normally-irrigated (NI) and water-stressed (WS) alfalfa exposed to O_3 in Shafter, CA, 1985, for each exposure period.

Treatment[a]		Harvest Date						
		4/23	5/21	6/18	7/10	8/07	9/04	10/09
CF	NI	19.7	38.6	20.5	16.7	13.4	12.7	16.0
	WS	21.0	21.3	17.7	13.9	13.0	12.2	17.4
NF	NI	17.2	27.6	21.4	15.2	13.0	13.1	14.5
	WS	18.5	19.9	16.6	14.1	10.5	9.9	12.9
NF x 1.3	NI	13.2	23.6	19.3	15.0	11.2	11.2	13.1
	WS	17.2	19.8	16.9	13.9	9.8	10.4	11.5
NF x 1.7	NI	14.8	21.3	16.8	11.8	9.4	8.6	10.4
	WS	14.7	16.7	15.2	12.9	8.5	9.8	12.3
NF x 2.0	NI	13.9	24.2	16.9	12.7	9.6	9.5	10.7
	WS	15.3	19.2	14.4	12.1	8.7	8.6	14.8
AA	NI	22.7	28.7	18.4	16.3	12.5	13.6	12.0
	WS	21.6	20.2	17.8	13.5	13.5	12.9	13.1

[a] See footnote to Table 4.1.4.5.

Table 4.1.4.7. Harvest data for alfalfa grown in open-top chambers or plots at Shafter, CA, 1985. Data are in g m^{-2}; mean of three replicates (CF, NF, AA) or two replicates (NF x 1.3, 1.7, 2.0) per treatment.

	Harvest Date							
Treatment	4/23	5/21	6/18	7/10	8/07	9/04	10/09	Season
	I. Normal Irrigation							
CF	378	491	485	414	410	360	363	2902
NF	359	511	527	404	433	389	345	2971
NF x 1.3	279	405	419	392	348	312	313	2469
NF x 1.7	300	407	378	313	300	248	251	2198
NF x 2.0	283	375	372	329	295	266	258	2180
AA	457	505	467	434	434	394	298	2991
	II. Water-Stressed							
CF	345	336	309	395	254	243	212	1997
NF	308	339	302	303	238	200	187	1880
NF x 1.3	281	338	333	309	218	211	163	1854
NF x 1.7	255	326	300	282	194	197	171	1726
NF x 2.0	233	301	291	261	186	169	193	1636
AA	374	372	366	315	301	283	204	2217

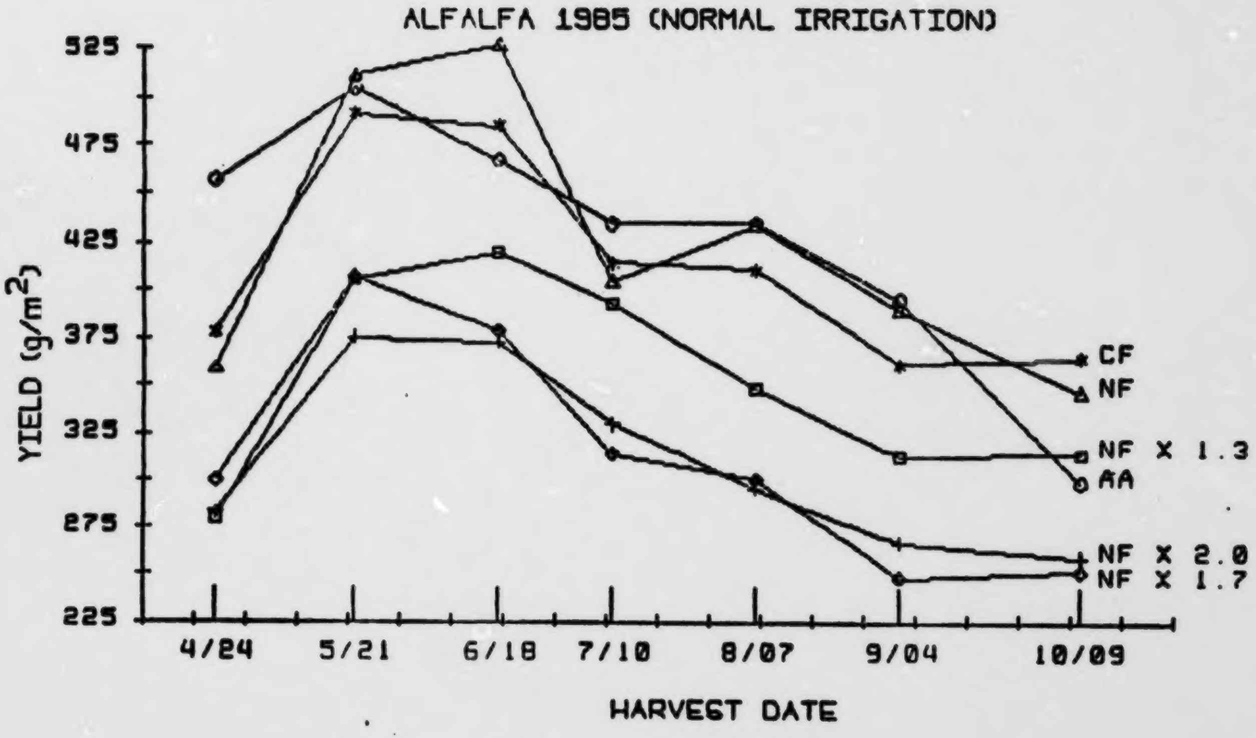

Figure 4.1.4.2. Yield (g m^{-2}) of normally irrigated alfalfa grown in open-top chambers or open (AA) plots exposed to a gradient of O_3 concentrations from 26 March to 9 October 1985; means of three (CF, NF, AA) or two (NF x 1.3, 1.7, 2.0) chambers or plots.

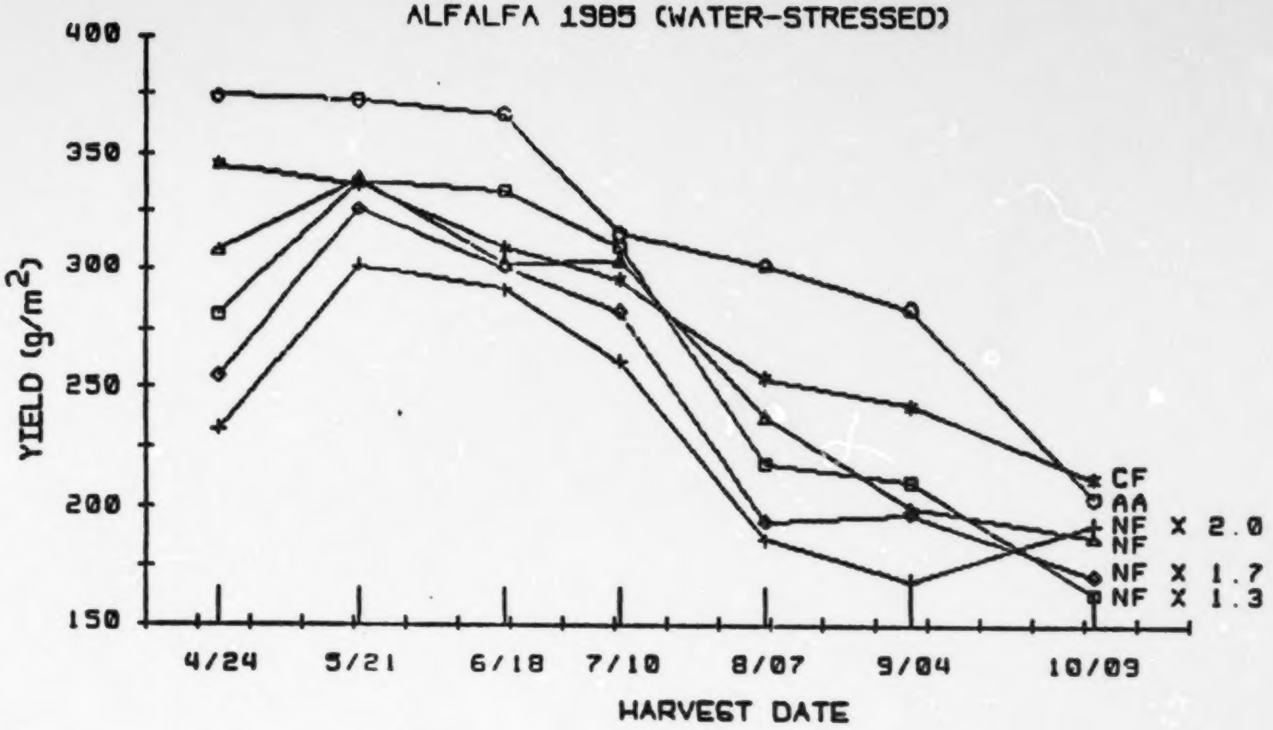

Figure 4.1.4.3. Yield (g m^{-2}) of water-stressed alfalfa grown in open-top chambers or open (AA) plots exposed to a gradient of O_3 concentrations from 26 March to 9 October 1985; means of three (CF, NF, AA) or two (NF x 1.3, 1.7, 2.0) chambers or plots.

between O_3 and irrigation was not statistically significant (Table 4.1.4.8.), as was also observed in 1984. Crown weights were also reduced by O_3 (Table 4.1.4.9.). Weight reductions in NI plots averaged -4.2, 16.3, 24.3, and 29.9 percent in NF, NF x 1.3, NF x 1.7, and NF x 2.0 treatments, respectively, compared with CF plots. Comparable weight reductions in WS treatments averaged 0.5, 12.3, 30.8, and 48.2 percent. Crown numbers were not significantly affected by either O_3 or drought stress. While both O_3 and water stress reduced crown weights, the interaction between the two was not statistically significant (Table 4.1.4.8.). However, when yield data from NI and WS plots were combined for regression analysis, the least squares best fit polynomial regression equation between total seasonal yield of alfalfa (Y) and seasonal 12-hr O_3 means $[O_3]$ contained a significant O_3 x irrigation term (Table 4.1.4.10.). Weibull function regression equations are also given in Table 4.1.4.10.

A comparison of seasonal yields of NI and WS plots in relation to seasonal 12-hr O_3 concentrations for 1984 and 1985 is shown in Figure 4.1.4.4. Yields in NI plots were similar for both years, and the yield response to O_3 was also similar for both years. For WS plots, yields in 1985 were lower than those in 1984, but the relative response to O_3 was similar in both years. No evidence of a residual effect of exposure to O_3 in 1984 was observed on accumulated yields in 1985.

Table 4.1.4.8. Analysis of variance mean squares for total seasonal yield and crown weights of alfalfa harvested in open-top chambers at Shafter, CA, 1985.[a/]

Source of Variation	df	Mean Squares Seasonal Yield	 Crown Dry Wt.
Ozone (O)	4	253236*	6087*
Irrigation level (I)	1	30303282***	4108*
O x I	4	44923	242
Error	14	64206	854
C.V. (%)		11.5	16.4

[a/] *Significant at 5.0% level.
***Significant at 0.1% level.
Ambient air plots were not included in this analysis.

Table 4.1.4.9. Seasonal yield and crown weights of alfalfa grown in open-top chambers or open plots at Shafter, CA, 1985. Data are means of three (CF, NF, AA) or two (NF x 1.3, 1.7, 2.0) replicate treatments.

	Normal irrigation		Water-stressed	
Treatment	Yield (g m^{-2})	Crowns (g)	Yield (g m^{-2})	Crowns (g)
CF	2902	214	1997	195
NF	2971	223	1880	194
NF x 1.3	2469	168	1854	171
NF x 1.7	2198	148	1726	135
NF x 2.0	2180	150	1636	101
AA	2991	204	2217	198

Table 4.1.4.10. Linear and Weibull model regression equations for seasonal 12-hr O_3 concentrations and total seasonal yield and crown dry weights of alfalfa grown in open-top chambers in Shafter, CA, 1985. Numbers in parentheses are ±1 standard error of the estimated parameter.

A. Linear Models

Yield, g m^{-2}, d.m.

$$y = 1987 + \underset{(\pm 144)}{1081\, I} - \underset{(\pm 16241)}{41411\, [O_3]^2} - \underset{(\pm 2396)}{6119\, ([O_3] \times I)} \qquad R^2 = 0.88$$

Crown d.m.

$$y = 205 + \underset{(\pm 9.8)}{29.4\, I} - \underset{(\pm 1555)}{11172\, [O_3]^2} \qquad R^2 = 0.74$$

B. Weibull models

Yield g m^{-2}

$$y = (\underset{(\pm 132)}{2091} + \underset{(\pm 111)}{817\, I})\, e^{-\left(\frac{[O_3]}{\underset{(\pm 0.127)}{0.234}}\right)^{\underset{(\pm 0.85)}{1.38}}}$$

Crown d.m.

$$y = (\underset{(\pm 11.6)}{195} + \underset{(\pm 12.6)}{28\, I})\, e^{-\left(\frac{[O_3]}{\underset{(\pm 0.015)}{0.118}}\right)^{\underset{(\pm 1.21)}{2.85}}}$$

I = 0 if normally watered plots.

I = 1 if water-stressed plots.

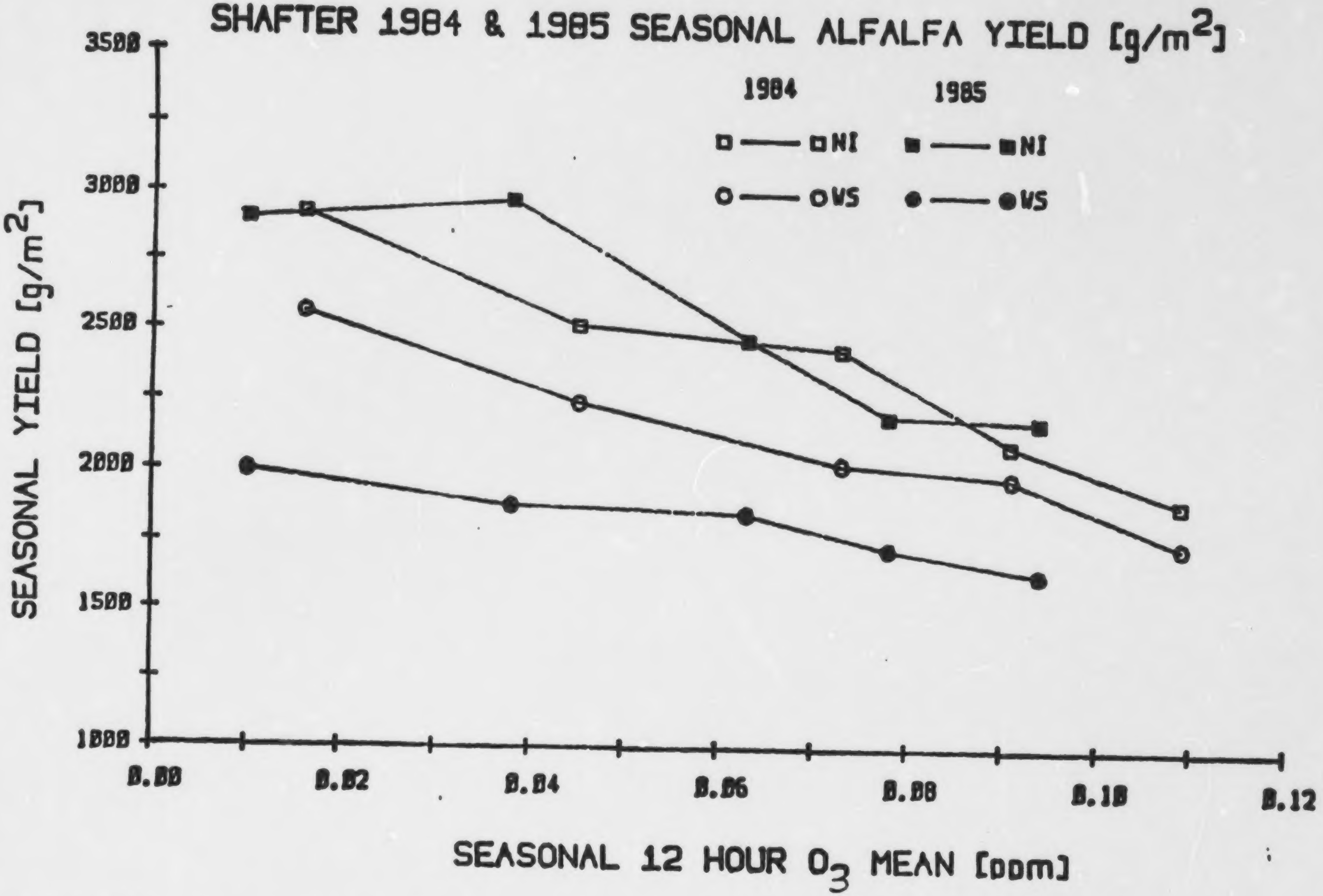

Figure 4.1.4.4. Seasonal yield (g m^2) of normally-irrigated (NI) and water-stressed (WS) alfalfa exposed to gradient of O_3 concentrations from 16 March to 10 October 1984 and from 26 March to 9 October 1985; means of three (CF, NF) or two (NF x 1.3, NF x 1.7, NF x 2.0) chambers per treatment.

4.1.5. Growth and Yield Responses of Differentially-Irrigated Cotton to O_3 (SWRCLAP)--P. J. Temple, R. S. Kupper, R. W. Lennox and O. C. Taylor

4.1.5.1. Introduction

Previous field studies of the interaction between ozone (O_3) and water stress on physiological responses and growth of crops have shown that these interactions were complex functions of soil moisture, evapotranspiration, plant phenology, and O_3 exposure dynamics. These studies have all used two levels of soil moisture; one in which plants received adequate or optimum water supply, and one in which plants were given less than optimum amounts of water. The degree of water stress imposed on those plants receiving sub-optimum irrigation depended upon environmental conditions during the growing season. In order to fully characterize the relationship between plant water status and response to O_3, a wider range of soil moisture conditions should be used. The objectives of this study were to develop techniques for exposing field-grown plants in open-top chambers to a range of soil moisture levels; and to determine dose-response relationships between O_3 and cotton grown under a range of soil moisture conditions.

4.1.5.2. Materials and Methods

Ozone treatments. Cotton plots were established at the University of California, Riverside Experimental Farm in 1985. The field site soil, in the Hanford coarse sandy loam series (Coarse-loamy, mixed, non-acidic, thermic, Typic Xerorthents), was fumigated with ethylene bromide for nematode and weed control in February 1985. Ammonium nitrate fertilizer was broadcast over the field at a rate of 112 kg/ha and cultivated into the soil on 8 July. Subsequent soil analyses for fertility levels indicated that all measured nutrients were within optimal levels for production of cotton. Planting beds spaced 75 cm apart were shaped by tractor and on 10 July "Acala SJ-2" cotton was planted at 7.6 cm spacing to provide a density of 175,000 plants/ha. This planting date was about two months later than the normal planting date for cotton in this area. Delays in obtaining the equipment necessary to complete construction of the new open-top chamber field facility in Riverside precluded an earlier start to the experiment. The field was maintained on sprinkle irrigation until emergence and establishment of the crop. Thirty individual plots were marked off in a 6 by 5 array on 19 July. Each plot was 4.6 m x 5.6 m and consisted of six rows of cotton, 5.6 m long. The center two rows were the sample rows; two guard rows were inside the chamber and two were outside the chamber walls. On August 16, when the plants were in the 2 to 3 true leaf stage, 24 cylindrical open-top chambers, each 3 m in diameter by 2 m high, equipped with a fustrum that restricted the top opening to 1.94 m in diameter, were centered on randomly selected plots. The six additional plots served as ambient air (AA) controls. Chamber blowers were set to start at 0600 and shut off at 2200.

Chambers were randomly assigned to four O_3 treatments as follows: charcoal-filtered (CF); nonfiltered (NF); O_3 addition to attain 1.25 times ambient (NF x 1.25); and NF times 1.50 ambient O_3 (NF x 1.5). Additions were proportional to O_3 concentrations detected 3 m above ground level by a continuous ambient O_3 monitor (Model 1003-AH, Dasibi Co., Glendale, CA). Additions of O_3 began at 0900 and continued until 2100, whenever ambient O_3 exceeded 0.03 ppm. Ozone additions began on 31 August and continued daily until harvest. Ozone monitors were calibrated weekly with a transfer standard calibrated by the California Air Resources Board with a primary O_3 standard. Ozone monitors, data acquisition, and data quality assurance procedures were the same as those used previously, except that acquisition and storage of chamber and ambient O_3 concentrations used a Keithley System 500 D.A.S. (Keithley Corp., Cleveland, OH) and an Apple Model II+ P.C.

All sample lines were calibrated at the beginning of the dispensing season. The calibration procedure used a stable O_3 source which was placed inside each chamber, then the O_3 concentration through the sample line was compared with that of an identical line whose efficiency had been well- characterized. All sample lines were calibrated at three O_3 concentrations: 0.20 ppm, 0.10 ppm, and 0. Sample lines whose O_3 delivery efficiency did not agree with the known line within ±10% were replaced.

Meteorological data were obtained from a National Weather Service station located on the University of California-Riverside campus, about 1 km east of the field plots.

Irrigation treatments. Ozone treatments were divided at random into equal numbers of optimally irrigated (optimal), sub-optimally irrigated (intermediate), and severely stressed (stressed) treatments. On 7-12 August, a drip-tape irrigation system was installed in each plot, and the systems were calibrated in the following manner. At each plot, the water from each of the six lengths of drip tape was collected over a known period of time (1 to 3 minutes). The volume of water from each tape was measured and recorded. In plots where water delivery was greater than ±15 percent of the overall mean water delivery, either the pressure regulator for the plot was adjusted, or individual drip tapes were replaced.

Soil moisture was measured with a neutron probe (Model 3330, Troxler Electronics Labs, Sacramento, CA) at depths of 30 cm, 60 cm, and 90 cm. Access tubes 1.2-m long for neutron probe readings were installed near the center of each plot. Readings were begun on 10 September; however, on 14 September, the probe malfunctioned and was returned to the factory. Measurements were begun again on 11 October, and were made on a weekly basis thereafter. Plant water status was determined by pressure bomb (Plant Water Status Console, Model 3000, Soil Moisture, Inc., Santa Barbara, CA). Readings were taken at least weekly between 1200 and 1700 on three leaves from plants adjacent to the sample area in each plot. Readings of -1.8 MPa or lower were considered as evidence of plant water stress in optimal plots while readings were allowed to decrease to -2.0 and -2.2 or lower in intermediate and stressed plots, respectively. When mean values for each treatment reached these levels, water was applied to return the soil moisture to field capacity in optimal plots. Two-thirds of this amount was applied to intermediate plots and one-third to stressed plots. Total amount of irrigation water added to optimal, intermediate, and stressed plots was 107 cm, 82 cm, and 65 cm, respectively. Stomatal conductance was determined on 22 September, 10 October, and 4 November by measurement of abaxial and adaxial surfaces of the fourth leaf from the plant apex (the youngest fully-expanded leaf) on five plants in each CF, NF, and NF x 1.50 chamber. Measurements were taken between 1000 and 1400 with a steady-state porometer (LI-1600; Licor Inc., Lincoln, NB.

Pesticides were used periodically for control of aphids, mites, and lepidopteran larvae (Table 4.1.5.1.).

Harvest procedures. Plants were harvested from November 21-24. Although very few bolls had opened, the weather was too cool and wet to allow the bolls to mature in the field. The 4-m-row sample area was divided into four quadrants, and plants were cut individually at the soil level. Fresh weights of the bolls (greater than 2.5 cm in diameter), leaves and stems were taken immediately after cutting. Leaf areas were determined after weighing using a leaf area meter (Li-Cor Model #3100, LiCOR Corp., Lincoln, NB). The leaf meter was calibrated with a standard area disc every twentieth measurement. Leaf and stem samples were dried at 80°C and bolls were dried at 50°C until no weight change was detected. Oven-dry weights were determined immediately after removal from the dryer. All bolls opened during the drying process. All NCLAN quality assurance protocols regarding processing of biological samples were observed during harvest, weighing, and data collection.

Data analysis. Experimental data were analyzed in a completely randomized design with five levels of O_3 (four chambered treatments + AA plots), three levels of soil moisture, and two replicates of each treatment combination. Data were analyzed using analysis of variance and linear and non-linear (Weibull) regression models. Open (AA) plots were not included in the regression analyses. Preliminary analysis of variance indicated that positional effects inside chambers were not statistically significant, so individual quadrant harvest data were averaged for each plot to determine yield per meter-row.

4.1.5.3. Results

Air quality. The 12-hr mean ambient O_3 concentration (0800-2000) was 0.055 ppm for the O_3-dispensing period 31 August through 12 November, 1985. Treatment O_3 12-hr means for the same period were CF = 0.015 ppm; NF = 0.050 ppm; NF x 1.25 = 0.062 ppm; NF x 1.50 = 0.075 ppm. Frequency distributions for ambient O_3 and chamber O_3 concentrations are given in Table 4.1.5.2. The seasonal pattern of 12- and 24-hr daily O_3 means are shown in Figure 4.1.5.1. Ambient O_3 was highly episodic during this period, with peak episodes separated by 4- to 8-day intervals of relatively low O_3 concentrations.

Injury responses. Ozone injury symptoms consisting of chlorotic mottle and general chlorosis of the oldest leaves appeared 11 days after the start of O_3 additions. These symptoms first appeared in three NF x 1.5 plots, including both optimal and one stressed plot. As the season

Table 4.1.5.1. Summary of significant events in exposure of "Acala SJ-2" cotton to O_3 at Riverside, 1985.

Date	Event
2/10-20	Field fumigated with methyl bromide
7/8	Ammonium nitrate applied (112 kg ha^{-1})
7/10	Cotton "Acala SJ-2" seeded at 7.6-cm spacings
7/17	Emergence of cotton seedlings
8/14-15	Calibration of drip tape system
8/16	Chambers placed on plots; blowers on 0600-2200
8/23	BT sprayed at 1.0 l ha^{-1}
8/29	BT sprayed at 1.0 l ha^{-1}
8/31	Ozone additions began from 0800-2000
9/6	First flowers opened
9/11	First appearance of O_3 injury symptoms on leaves
9/27	Malathion applied at 1.9 l ha^{-1}
10/18-22	Spot spraying with malathion at 1.9 l ha^{-1}
10/27	Kelthan applied at 0.5 l ha^{-1}
11/5	Spot spraying with kelthan at 0.5 l ha^{-1}
11/12	Last day of O_3 additions
11/21-24	All treatments harvested

Table 4.1.5.2. Frequency distributions of hourly ambient and chamber O_3 concentrations recorded in Riverside from 31 August to 12 November 1983.

Total Observations	AA (1765)[a/]	CF (9612)[a/]	NF (9614)[a/]	NF1.25 (9612)[a/]	NF1.50 (9613)[a/]
.000<= OB <=.010	311(17.6%)	4099(42.6%)	2223(23.1%)	2203(22.9%)	1998(20.8%)
.010 < OB <=.020	547(31.0%)	3893(40.5%)	2725(28.3%)	2362(24.6%)	2382(24.8%)
.020 < OB <=.030	253(14.3%)	1370(14.3%)	1352(14.1%)	1054(11.0%)	842(8.8%)
.030 < OB <=.040	170(9.6%)	214(2.2%)	805(8.4%)	753(7.8%)	544(5.7%)
.040 < OB <=.050	93(5.3%)	27(0.3%)	469(4.9%)	579(6.0%)	529(5.5%)
.050 < OB <=.060	79(4.5%)	8(0.1%)	451(4.7%)	485(5.0%)	473(4.9%)
.060 < OB <=.070	77(4.4%)	0(0.0%)	373(3.9%)	417(4.3%)	384([illegible].0%)
.070 < OB <=.080	58(3.3%)	1(0.0%)	323(3.4%)	332(3.5%)	406(4.2%)
.080 < OB <=.090	39(2.2%)	0(0.0%)	227(2.4%)	283(2.9%)	335(3.5%)
.090 < OB <=.100	50(2.8%)	0(0.0%)	260(2.7%)	293(3.0%)	341(3.5%)
.100 < OB <=.110	32(1.8%)	0(0.0%)	136(1.4%)	254(2.6%)	292(3.0%)
.110 < OB <=.120	16(0.9%)	0(0.0%)	79(0.8%)	167(1.7%)	202(2.1%)
.120 < OB <=.130	11(0.6%)	0(0.0%)	45(0.5%)	106(1.1%)	241(2.5%)
.130 < OB <=.140	8(0.5%)	0(0.0%)	29(0.3%)	91(0.9%)	168(1.7%)
.140 < OB <=.150	2(0.1%)	0(0.0%)	36(0.4%)	55(0.6%)	98(1.0%)
.150 < OB <=.160	7(0.4%)	0(0.0%)	22(0.2%)	50(0.5%)	93(1.0%)
.160 < OB <=.170	5(0.3%)	0(0.0%)	21(0.2%)	24(0.2%)	70(0.7%)
.170 < OB <=.180	1(0.1%)	0(0.0%)	9(0.1%)	30(0.3%)	54(0.6%)
.180 < OB <=.190	3(0.2%)	0(0.0%)	9(0.1%)	34(0.4%)	36(0.4%)
.190 < OB <=.200	1(0.1%)	0(0.0%)	7(0.1%)	13(0.1%)	34(0.4%)
.200 < OB <=.210	1(0.1%)	0(0.0%)	9(0.1%)	7(0.1%)	36(0.4%)
.210 < OB <=.220	1(0.1%)	0(0.0%)	4(0.0%)	3(0.0%)	17(0.2%)
.220 < OB <=.230	0(0.0%)	0(0.0%)	0(0.0%)	1(0.0%)	3(0.0%)
.230 < OB <=.240	0(0.0%)	0(0.0%)	0(0.0%)	8(0.1%)	12(0.1%)
.240 < OB <=.250	0(0.0%)	0(0.0%)	0(0.0%)	7(0.1%)	4(0.0%)
OB >.250	0(0.0%)	0(0.0%)	0(0.0%)	1(0.0%)	19(0.2%)

[a/] Number of observations for each treatment

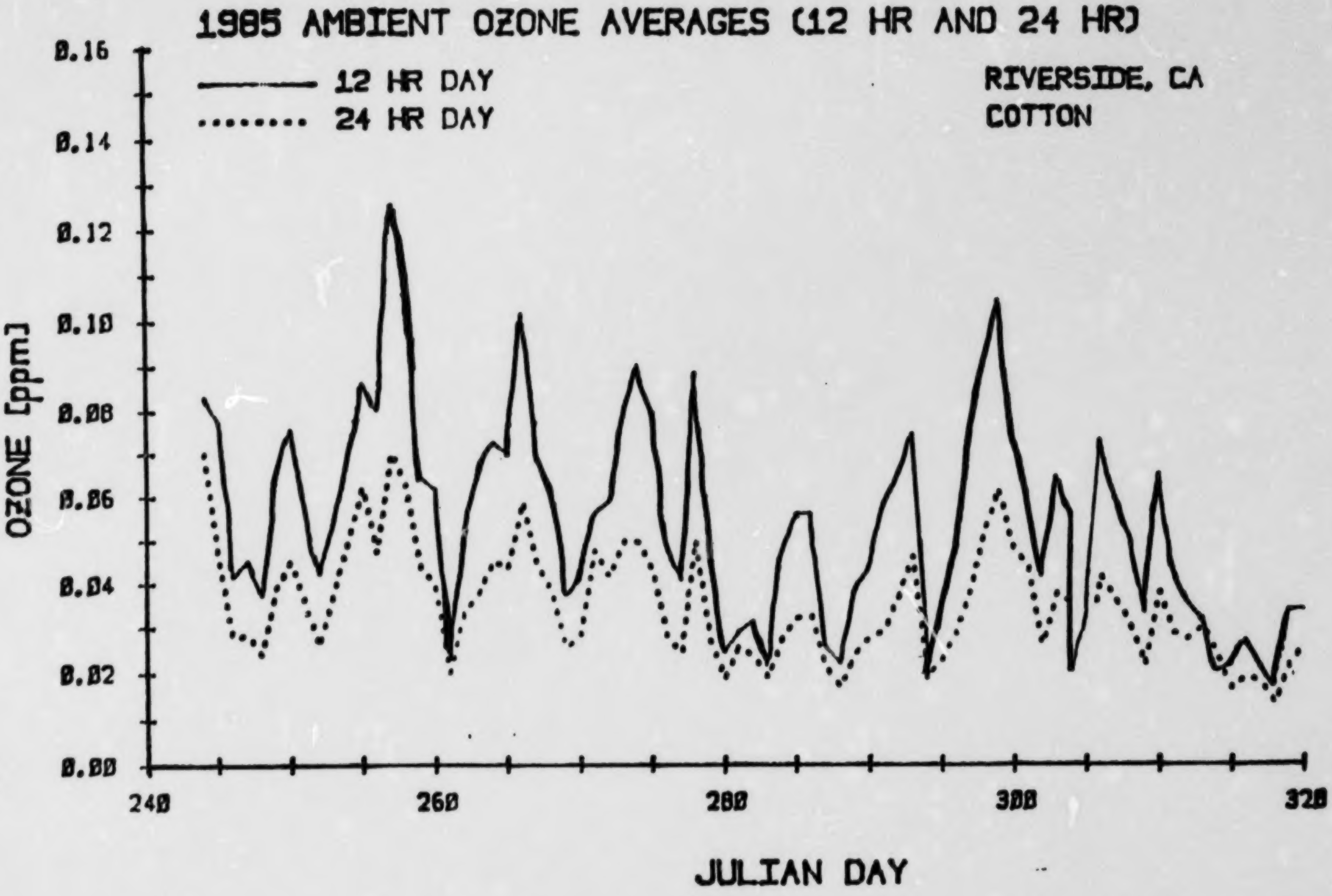

Figure 4.1.5.1. Daily mean 12- and 14-hr ambient O_3 concentrations in Riverside, CA, 31 August through 12 November, 1985.

progressed, symptom severity increased to premature senescence and abscission of severely injured leaves. Ozone injury later appeared in all NF x 1.5 plots and in all optimal plots, except the CF. No symptoms were observed in the CF plots, or in intermediate and stressed AA plots. Injury symptoms were generally less evident in the drier plots.

Plant water status. Evidence of water stress (wilting) was first observed in the WS plots on 13 September, 20 days after their last irrigation. By 28 September, differences in plant height were apparent among the irrigation treatments. Xylem pressure potential (ψ_1) (Figure 4.1.5.2.) and stomatal conductance measurements (Table 4.1.5.3.) confirmed that significant differences in plant water status were obtained among irrigation treatments. Maximum stomatal conductance in intermediate and severely stressed plots averaged 17.4% and 36.5% lower, respectively, than in optimally irrigated plots.

Yield responses. Harvest data are presented in Table 4.1.5.4. Exposure to O_3 in this experiment did not reduce boll number, boll fresh weight, boll dry weight, lint weight or seed weight. However, there was a reduction in leaf area, leaf fresh weight, and leaf dry weight. Stem fresh weight increased with O_3 exposures. Production of vegetative plant parts was greater in AA plots than in chamber plots, while production of bolls, lint, and seed was reduced in AA plots. This may have been due to temperature differences or to a low level of bollworm infestation in the AA plots. Growth and yield decreased for all harvest measurements with increased water stress. Intermediate and dry plots averaged 36.7 and 43.7 percent lower leaf area, respectively, compared with optimally-irrigated plots. Reductions in other vegetative growth characteristics were comparable. Boll number was reduced 18.3 and 34.0 percent, respectively. Reductions in lint and seed weight were less pronounced, averaging 13.6 and 16.2 percent for lint weight and 10.0 and 11.9 percent for seed weight in intermediate and stressed plots, respectively, compared with optimal plots.

Analysis of variance showed that the O_3 effect was not statistically significant for any character evaluated (Table 4.1.5.5.). The irrigation treatment effect was significant for boll number, boll fresh weight, leaf area, and leaf fresh weight. The interaction effect between O_3 and irrigation was not significant for any character. Regression analysis confirmed that only the irrigation term was significantly correlated with yield measurements. Seasonal O_3 means or irrigation x O_3 interaction terms were not statistically significant. Parameters for the Weibull regression model could not be calculated because the equation did not converge.

Discussion and conclusions. Cotton in this experiment was grown under three water regimes: optimally irrigated plots were watered when xylem pressure potentials (ψ_1) reached -1.8 MPa at noon, sub-optimally irrigated plots were allowed to dry until ψ_1 reached -2.0 MPa, and water-stressed plots were allowed to dry to a ψ_1 of -2.2 MPa. In this experiment, a significant O_3 effect on yield was not observed. Ozone injury symptoms were observed on the leaves, but this injury may not have been severe enough to affect boll yield. This may have been a result of

Table 4.1.5.3. Mean maximum total (abaxial + adaxial) stomatal conductance of cotton grown under three soil moisture regimes in Riverside, CA, 1985; means of 3-5 plants per chamber. Data were collected on 22 September, 10 October, and 4 November 1985.

O_3 Treatment[a]	Soil Moisture Regime		
	Optimum	Intermediate	Stressed
CF	1.40	1.08	0.73
NF	1.00	0.81	0.57
NF x 1.50	1.04	0.97	0.88

[a] Data were not collected from NF x 1.25 plots.

Table 4.1.5.4 Mean harvest data (per meter row) by O_3 and irrigation level for cotton grown in open-top chambers at Riverside, CA, 1985.

Treatment	Boll Number	Boll Fresh Weight (g)	Boll Dry Weight (g)	Lint Weight (g)	Seed Weight (g)	Leaf Area (cm^2)	Leaf Fresh Weight (g)	Leaf Dry Weight (g)	Stem Fresh Weight (g)
Ozone level[a/]									
CF	26.0	634	119	24.3	43.4	10456	403	93.8	333
NF	24.0	577	113	23.9	42.3	9530	341	81.6	339
NF x 1.25	25.3	610	115	23.7	41.3	9558	331	78.2	369
NF x 1.50	25.8	643	119	26.0	44.3	8849	306	71.7	386
AA*	18.7	455	76	11.6	21.9	10832	424	101.1	516
Irrigation level[b/]									
Optimum	30.6	820	135	27.2	46.2	13111	457	102.9	554
Intermediate	25.0	573	113	23.5	41.6	8297	303	73.1	296
Stressed	20.2	456	102	22.8	40.7	7386	276	68.0	221

*AA data not included in irrigation level means.

[a/] Data averaged across irrigation levels

[b/] Data averaged across O_3 levels (AA plots not included).

Table 4.1.5.5 Analysis of variance mean squares for cotton (per meter row) harvested in open-top chambers in Riverside, CA, in 1985.

Source	df	Mean Squares								
		Boll Number	Boll Fresh Weight (g)	Boll Dry Weight (g)	Lint Weight (g)	Seed Weight (g)	Leaf Area (cm^2)	Leaf Fresh Weight (g)	Leaf Dry Weight (g)	Stem Fresh Weight (g)
Ozone	3	4.9	5254	50	6.9	10.1	2606646	10093	514	3739
Irrigation (I)	2	215.8*	275600	2185	45.8	69.9	75700350*	75444*	2847	243286***
I x O	6	12.2	15037	482	20.7	68.8	4176228	5927	280	6823
Error	12	41.3	40276	989	39.1	106.9	1466120	17405	849	17684

*, *** = Significant at the 5% and 0.1% levels, respectively.

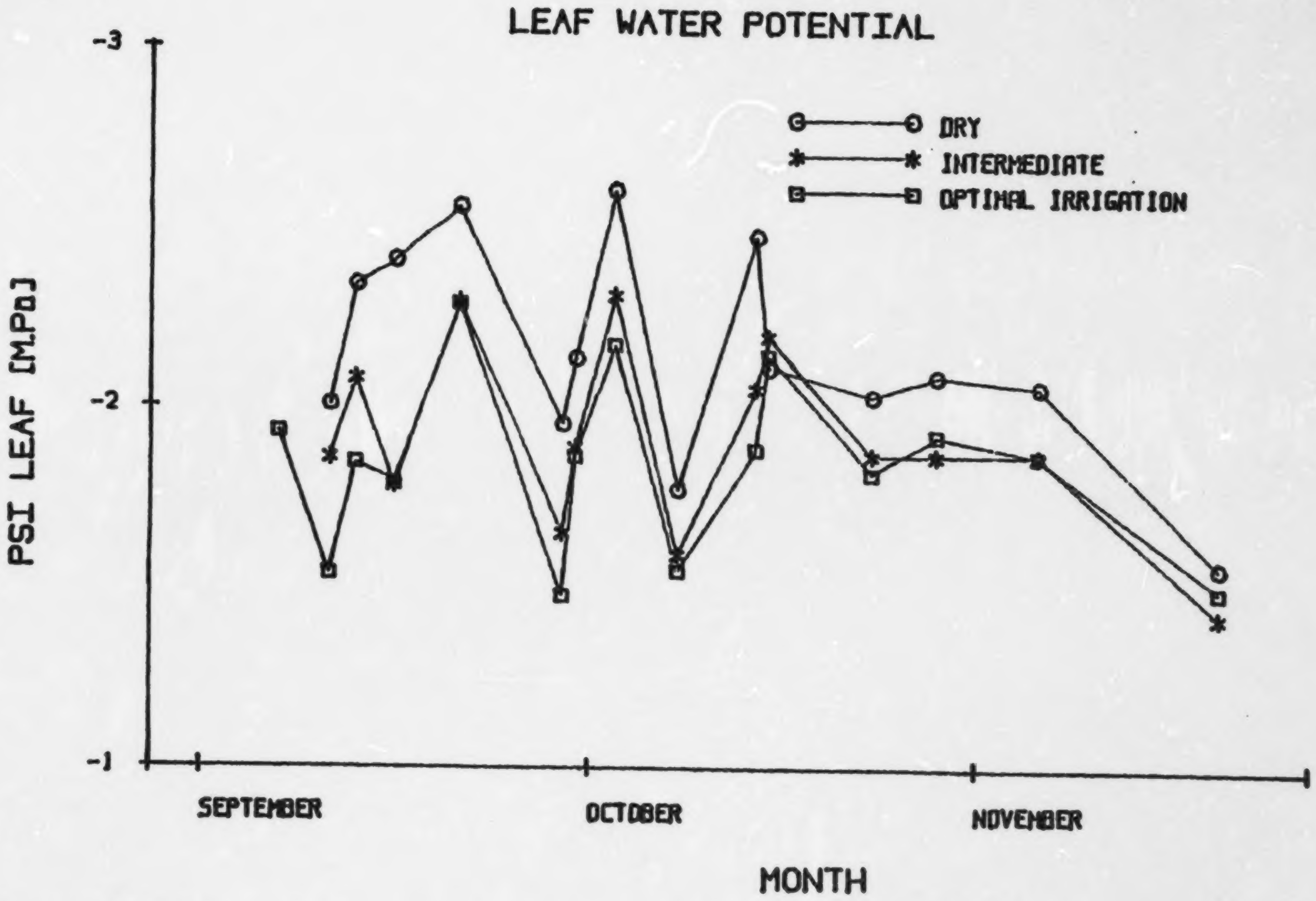

Figure 4.1.5.2. Mean xylem pressure potentials (MPa) of differentially irrigated cotton grown in open-top chambers in Riverside, 1985.

the lower than average ambient O_3 during the latter half of the 1985 growing season. Because of the late planting date, the cotton crop matured in the fall, when O_3 concentrations were relatively low. Another factor may have been the poor overall yield due to cool, wet autumn weather.

Significant differences in plant water status as determined by physiological measurements as well as differences in plant growth and yield were found in the three soil water treatments. This suggests that an irrigation system based on calibrated drip tapes can be employed successfully in a factorial experiment to test the interactive effects of multiple levels of O_3 and soil moisture on plant growth and yield.

4.2. Effects of SO_2 and O_3 on Dose-Response Relationships

4.2.1. Effects of O_3 and SO_2 on the Physiology and Yield of a Crop of Red Clover and Timothy: Part II (NERCLAP)--Robert Kohut, Robert Amundson, and John Laurence

4.2.1.1. Introduction

The 1985 NCLAN field program at Boyce Thompson Institute was the second year of a two-year study on mixed forage and was the third year of a three-year program that integrated crop loss studies sponsored by the Environmental Protection Agency and the Electric Power Research Institute. The goals of the 1985 study were to 1) evaluate dose-response relationships for yield of the red clover and timothy hay crops exposed to O_3 and SO_2 alone, and the two pollutants combined; 2) assess nutrient qualities of the crop harvested from the air pollutant treatments; and 3) assess the effects of the treatments on chlorophyll content and photosynthesis of timothy.

4.2.1.2. Materials and Methods

Cultural Practices. A mixed stand of hay consisting of red clover (*Trifolium pratense* L. cv. 'Arlington') and timothy (*Phleum pratense* L. cv. 'Champlain') was drilled on 16 August 1983. The field had been pretreated with Round-up herbicide at 7.1 l/ha and fertilized with 10-20-20 (NPK) at 227 kg/ha. Seed of the two species was combined at equal weights and applied at a rate of 14.75 kg/ha. The ratio of timothy to clover seed was approximately 4.5:1. Prior to planting, the clover seed was inoculated with Nitragin, a commercial rhizobium product, at the rate of 41 g/kg of seed.

Soils in the experimental plot are in the Collamer and Niagara series, both of which are Haplaudalfs. The soils are characterized as silt loams. Tensiometers were placed in all plots at a depth of 30.5 cm to monitor soil moisture. Readings were taken two times each week and all plots irrigated when readings began to exceed 70 in several plots. Irrigation was conducted on 11 and 12 June and on 13 and 14 August. All plots received 2.5 cm of water at both irrigations. Malathion was applied on 11 and 30 July to control aphids on the experimental plots. Slug poison was placed in each plot on 3 August.

Pollutant Treatments and Monitoring. The study used four levels of O_3, four levels of SO_2, and all combinations of the two pollutants. The O_3 treatments consisted of charcoal-filtered air (CF), nonfiltered air (NF), and nonfiltered air with the proportional addition of O_3 to attain 1.5 and 2.0 times the ambient concentration (NF x 1.5 and NF x 2.0, respectively). Additions were made for 12-hr/day (0800 to 2000 EDT) when ambient O_3 concentrations were greater than 0.03 ppm. Standard NCLAN protocols were followed for rain periods and blower shut-down at night.

Sulfur dioxide exposures simulated the concentration, duration, and frequency dynamics associated with point sources. Ambient SO_2 monitoring data were obtained from the Tennessee Valley Authority for the Shawnee

Steam Plant for the 1976, 1978, and 1982 growing seasons. Since each year represented a different level of emission control at the power plant, the frequency distribution of concentrations and the exposure dynamics for each year served as the basis for developing three SO_2 treatments used in 1984. Since the 1984 SO_2 treatments produced no effects on the timothy and red clover forage crop, the lowest SO_2 treatment level was dropped, the remaining two treatments were slightly modified, and a new higher level of SO_2 exposure was developed. The frequency distributions of the hourly SO_2 exposure concentrations are presented in Table 4.2.1.1. The fourth treatment level consisted of no SO_2 addition.

The O_3 and SO_2 generation and distribution systems were similar to those used in previous NCLAN studies. Ozone monitoring was conducted with Monitor Labs Model 8410 instruments and SO_2 was monitored with TECO Model 43 instruments. All monitors were subject to the NCLAN quality assurance program. Pollutant monitoring used a time-sharing system where each observation was 1.5-min in duration and each plot was sampled three times an hour. The sample stream was split after passing through the sequencing valve and entered both the O_3 and SO_2 monitors. All sample lines were Teflon. Line efficiencies were determined two times during the study and were taken into account during the fumigations and the reduction of monitoring data. Monitoring data were recorded with a Hewlett-Packard Model 85 computer and data logger with strip-charts used as back-up.

The forage stand was evaluated for uniformity in the Fall of 1984 and 36 new plots were selected. The experiment was a 4 x 4 x 2 factorial requiring 32 open-top chamber plots. The four additional plots were ambient air. Treatments were randomly assigned to 18 plots in each of two blocks. A pretreatment harvest of each experimental plot was conducted on June 3 and 4 at clover flowering to establish baseline yield and quality values. Plastic was placed on the chamber frames and blowers started by June 11. Ozone treatments were initiated on 14 June. The final fumigation of the study was conducted on 9 October. During this 118 day period, O_3 additions were made on 91 days and SO_2 exposures were conducted on 30 days.

Treatment harvests were conducted on 13 and 14 August and 9 October. Harvest data were obtained from two permanently marked 0.5 m^2 quadrats in each chamber and ambient plot. Plants in each quadrat were cut approximately 10 cm above the ground and immediately separated by species. Plant material was oven-dried at 80° C for 48 hr, weighed, and analyzed for nutrient content and elemental composition.

Samples of timothy and red clover from the pretreatment and the two treatment harvests were subjected to nutrient and elemental analysis. Variables evaluated included crude protein, available protein, acid detergent fiber, total digestible nutrients, estimated net energy, calcium, phosphorus, magnesium, potassium, sodium, iron, zinc, copper, manganese, and sulfur. Analyses were conducted by the Forage Testing Laboratory of the New York Dairy Herd Improvement Cooperative in Ithaca, NY.

Table 4.2.1.1. Frequency distributions of the hourly SO_2 concentrations in the three target treatments used in the 1985 forage study at Ithaca, NY.

SO_2 Concentration (ppm)	Number of Hours of Exposure		
	High	Medium	Low
0	2376	2396	2450
.10	16	33	31
.15	20	20	13
.20	13	10	5
.25	10	8	3
.30	10	7	5
.35	10	6	3
.40	8	5	3
.45	8	6	2
.50	10	6	
.55	8	4	
.60	7	5	
.65	6	4	
.70	4	4	
.75	4	3	
.80	5	3	
.85	3		
.90	2		
Total hours of exposure	144	124	65

Physiology. Because there were 16 treatments, evaluations of changes in rates of photosynthesis were made only on timothy in 1985. The studies were conducted between the first and second harvests when the plants were growing most rapidly and ambient O_3 concentrations, and consequently all O_3 treatment levels, were the highest. Rates of photosynthesis were determined on the three youngest leaves immediately below the inflorescence (leaves 1, 2, and 3 in order of increasing age). Chlorophyll content of leaf blades 2 and 3 were also determined. Because of age-dependent differences in the two variables being evaluated, all comparisons of the effects of the treatments were made on leaves of the same age. The lengths of the leaf blades were measured at each assessment of photosynthesis and chlorophyll.

Rates of photosynthesis were assessed with two techniques: the uptake of $^{14}CO_2$ and the evolution of O_2. The rate of CO_2 fixation was assessed by exposing a portion of an intact leaf to an atmosphere with known CO_2 concentration and $^{14}CO_2$ activity for a fixed period to time. A disc was immediately excised and put into a solubilizing liquid and then placed in a scintillation counter to determine the activity of the ^{14}C tissue. The amount of ^{14}C present in the tissue is proportional to the rate of CO_2 fixed during the exposure interval (24).

Rates of oxygen evolution were determined on leaf discs cut 1 - 2 cm basal to the $^{14}CO_2$ sampled tissue. Leaf discs (0.33 cm^2) were cut from selected leaves with a hole punch and transferred to a temperature-controlled glass sample cell (Gilson Medical Electronics #01271002) containing a solution of 0.33M sucrose, 50 mM Hepes (pH 7.6), 10 mM $NaHCO_3$ and 1 µl Tween 20. The sample cell volume was 2 ml. Leaf discs were submerged in a 25° C solution and held perpendicular to a light source (Fiber-Lite, Bausch and Lomb) by 22-gauge wire. Oxygen evolution was determined polarographically using an O_2 electrode (YS1 #5331 oxygen probe) with a polarizing voltage of 0.8 volts. Oxygen consumption (respiration) was determined by completely darkening the cell and following the loss of O_2 from the solution. Probe sensitivity and span calculations were determined at the beginning and end of each day by measuring electrode output in H_2O equilibrated with ambient O_2 at 25° C and H_2O depleted of O_2 by the addition of 1.0 mg $Na_2S_2O_4$.

Following the measurement of O_2 evolution, the discs were transferred to test tubes containing 2 ml of 80 percent acetone and held on ice for chlorophyll determinations. Leaf discs were ground in cold 80 percent acetone by a "polytron" (Type PT10/35 Brinkman Instruments) for 30 seconds. The liquid sample was quantitatively transferred to a centrifuge tube and centrifuged at 7300 rpm for 5 minutes (Model CL, International Clinical Centrifuge). All samples remained on ice during preparation. Spectrophotometric determinations of chlorophyll concentrations were made on samples at room temperature (approx. 22° C) using a Perkin-Elmer Lambda 5 UV/visibile spectrophotometer that measured absorbance at A647 and A667. Chlorophyll a and b concentrations were calculated using the equation of Arnon.

Dose-response. The dose-response analyses used the harvest data from the 16 treatments of O_3 and SO_2 in the open-top chambers. Analyses were conducted using the yields of both species from each plot for the combined harvests. Regression analyses were conducted using the Weibull and alternative models to evaluate their suitability for the data.

4.2.1.3. Results

Pollutant Monitoring. The hourly O_3 and SO_2 monitoring data were analyzed to characterize the exposure treatments. The characteristics of the O_3 exposure treatments are presented in Table 4.2.1.2. The diurnal pattern of the seasonal hourly O_3 concentrations reflects the effects of the proportional controller and the extended daily fumigation period in the smooth transitions of increasing and decreasing O_3 concentrations in the O_3- addition treatments (Figure 4.2.1.1.). The cumulative frequency distributions of the hourly O_3 concentrations for each treatment during the 12-hr daily exposure period are presented in Figure 4.2.1.2.

The SO_2 treatments were characterized by calculating the average 24-hr concentration, the average daily 1-hr maximum concentration, the first and second 1-hr maximum concentrations, and the cumulative ppm hr. These data are presented in Table 4.2.1.3. Cumulative frequency distributions were developed from the 1-hr SO_2 exposure concentrations in each treatment (Figure 4.2.1.3.).

Effects of Ozone on Physiology. Tissues from the three youngest leaf blades below the inflorescence were sampled for $^{14}CO_2$ uptake, O_2 evolution, and chlorophyll content. For clarity, the leaves were designated 1, 2, and 3 in order of increasing age (Figure 4.2.1.4.). Ozone had no effect on the length of leaf blades 1, 2, or 3 (Table 4.2.1.4.) and no clear trends for effect of O_3 on chlorophyll contents of leaf blades 1, 2 and 3 were found (Table 4.2.1.5.).

Rates of $^{14}CO_2$ uptake were not influenced by O_3 in the youngest leaf, but as the leaves aged the absolute rates of $^{14}CO_2$ declined and the negative influence of O_3 increased with a trend for a linear reduction in leaf blade 2 ($P = 0.10$) and a significant linear reduction in leaf blade 3 ($P < 0.01$) (Figure 4.2.1.5.). Rates of O_2 evolution increased with exposure to higher concentrations of O_3 in leaf blades 2 and 3 (Figure 4.2.1.6.) and the ratio of O_2 evolved to $^{14}CO_2$ fixed increased with leaf age and dramatically increased with exposure to increasing concentrations of O_3 in leaves 2 and 3 (Figure 4.2.1.7.).

Effects of SO_2 on Physiology. Exposure to SO_2 significantly increased the lengths of leaf blades 1 and 2 (Figure 4.2.1.8.). The chlorophyll content per unit area of blade in leaves 2 and 3 tended to increase with exposure to the higher SO_2 concentrations (Table 4.2.1.6.). Even though the leaf blades were longer and tended to have more chlorophyll in the high SO_2 treatments, no trends for effects of SO_2 on $^{14}CO_2$ fixation were found (Table 4.2.1.7.). Rates of O_2 evolution doubled in leaves 2 and 3 only in the high SO_2 treatment (Table 4.2.1.8.). The ratio of O_2 evolution/$^{14}CO_2$ fixation increased only in the high SO_2 treatment for leaf blades 2 and 3 as a result of the high rates of O_2 evolution in these tissues.

Table 4.2.1.2. Treatment-level characterizations of the seasonal O_3 exposure regimes in the 1985 red clover and timothy study at Ithaca, NY. All concentrations in ppm.

	12-hr			7-hr			Daily 1-hr High Conc.				
Treatment	Avg	Max	2nd Max	Avg	Max	2nd Max	Avg	Max	2nd Max	Hr >.08	Hr >.12
CF	.019	.047	.037	.022	.052	.045	.038	.077	.076	0	0
AA	.036	.065	.064	.040	.069	.068	.052	.091	.087	13	0
NF	.036	.067	.066	.040	.072	.071	.052	.102	.090	16	0
NF x 1.5	.048	.094	.091	.054	.108	.103	.072	.163	.126	207	5
NF x 2.0	.062	.135	.133	.070	.146	.145	.098	.231	.192	548	156

Table 4.2.1.3. Treatment-level characterizations of the seasonal SO_2 exposure regimes in the 1985 red clover and timothy study at Ithaca, NY. All concentrations in ppm.

Treatment	24-hr avg for fumigation days	24-hr avg for all days	Avg daily 1-hr max for all days	Max 1-hr	2nd Max 1-hr	Cumulative ppm-hr[a/]
Ambient	.004	.002	.013	.121	.079	1.41
Low	.010	.006	.059	.484	.435	4.07
Medium	.025	.014	.127	.775	.767	10.75
High	.035	.020	.154	.970	.867	15.14

[a/] Calculated from the average SO_2 concentration for each fumigation.

Table 4.2.1.4. Effect of O_3 on length of leaf blades of timothy. The leaves were measured in conjunction with the $^{14}CO_2$ studies conducted 4 to 12 days before harvest 2.

Ozone Treatment	Leaf Blade Length (mm)		
	Leaf Blade Number		
	1	2	3
CF	(42)[a] 74.4 ± 2.9	(42) 169.9 ± 4.9	(16) 218.4 ± 10.0
NF	(42) 82.3 ± 3.4	(42) 180.4 ± 5.4	(17) 207.6 ± 10.4
NF x 1.5	(42) 85.5 ± 4.4	(42) 180.9 ± 8.0	(17) 212.4 ± 12.6
NF x 2.0	(42) 81.3 ± 3.5	(42) 181.4 ± 6.2	(17) 229.6 ± 8.2

[a] ( ) number of samples.

Table 4.2.1.5. Effect of O_3 on chlorophyll content of leaf blades of timothy. The measurements were made 4 to 12 days before harvest 2 on leaf discs taken to assess rates of O_2 evolution.

Ozone Treatment	Chlorophyll Content (μg chlorophyll/cm^2)		
	Leaf Blade Number		
	1	2	3
CF	(4)[a] 28.2 ± 4.0	(33) 31.3 ± 1.1	(12) 32.4 ± 2.0
NF	(5) 32.2 ± 1.9	(32) 30.5 ± 1.3	(12) 30.7 ± 1.6
NF x 1.5	(3) 27.9 ± 0.4	(32) 29.4 ± 1.0	(12) 31.0 ± 2.0
NF x 2.0	(3) 36.0 ± 4.1	(32) 33.5 ± 1.3	(12) 29.3 ± 2.5

[a] ( ) Sample number.

Table 4.2.1.6. Effect of SO_2 on chlorophyll contents of leaf blades of timothy. The measurements were made on leaf discs taken 4 to 12 days before harvest 2 to assess rates of O_2 evolution.

SO_2 Treatment	Chlorophyll Content (μg chlorophyll/cm^2) Leaf Blade Number 1	2	3
Control	(12)[a] 29.8 ± 1.6	(49) 30.1 ± 0.8	(16) 30.9 ± 1.8
Low	(3) 36.0 ± 4.1	(25) 31.3 ± 1.5	(16) 28.2 ± 1.8
Medium	(0)	(36) 32.1 ± 1.3	(16) 33.5 ± 1.5
High	(0)	(35) 32.0 ± 1.0	(16) 35.3 ± 1.8

[a] ( ) Sample number.

Table 4.2.1.7. Effect of SO_2 on photosynthesis of leaf blades of timothy. Measurements were made 4 to 12 days before harvest 2.

SO_2 Treatment	Photosynthesis (mg CO_2)/dm^2/h) Leaf Blade Number 1	2	3
Control	(35)[a] 16.71 ± 0.82	(51) 14.20 ± 0.64	(16) 10.94 ± 1.34
Low	(25) 16.44 ± 0.57	(25) 12.53 ± 0.98	(19) 9.70 ± 1.33
Medium	(19) 21.14 ± 1.02	(35) 16.24 ± 0.99	(16) 10.12 ± 0.93
High	(40) 17.63 ± 0.89	(56) 13.78 ± 0.73	(16) 9.89 ± 1.38

[a] ( ) Sample number.

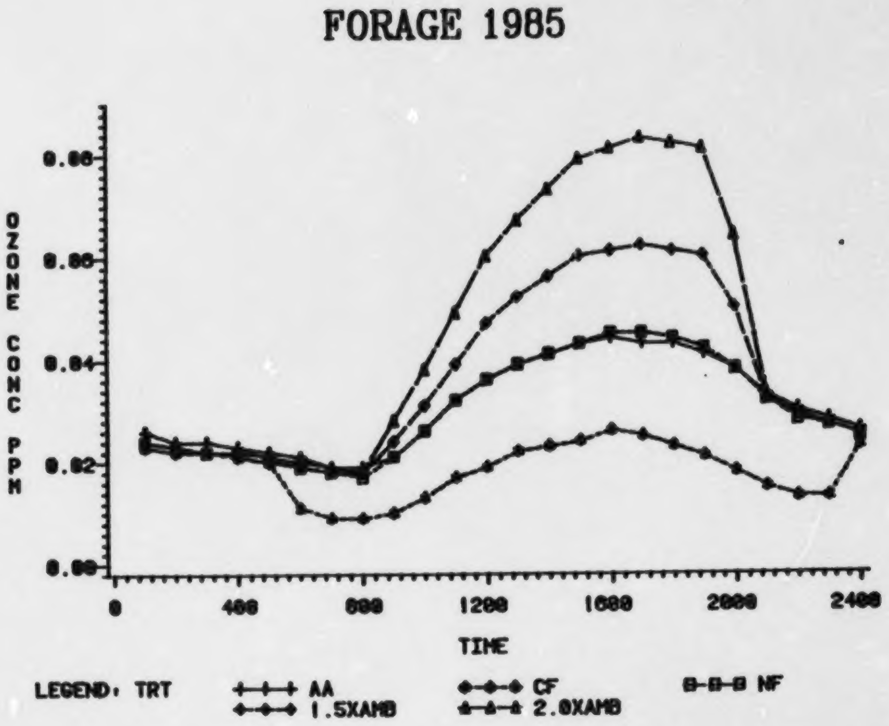

Figure 4.2.1.1. Diurnal pattern of the hourly concentrations of O_3 for each treatment level during the red clover and timothy experiment in 1985 at Ithaca, NY.

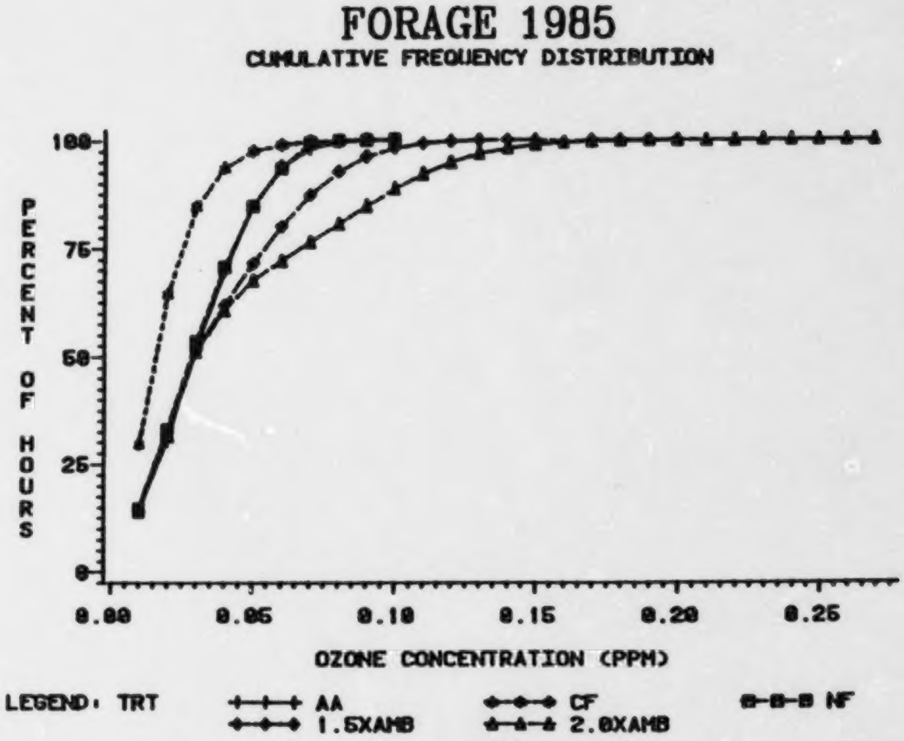

Figure 4.2.1.2. The cumulative frequency distributions of the hourly concentrations of O_3 produced with the proportional controller during the daily 12-hr exposure period for the chamber and ambient treatments.

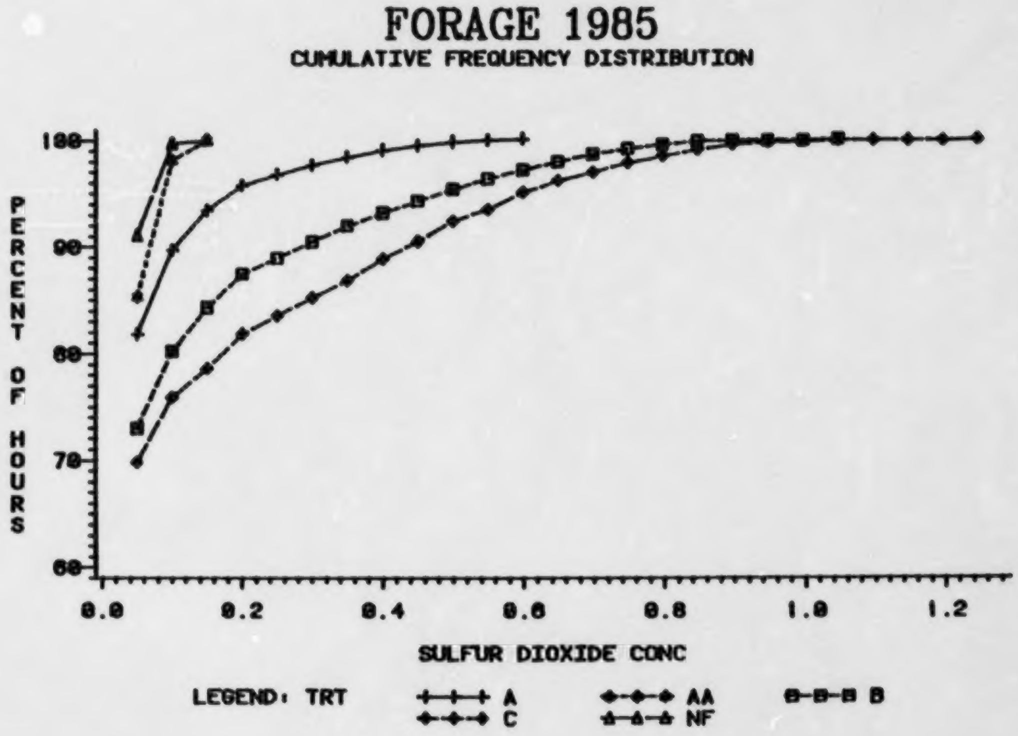

Figure 4.2.1.3. The cumulative frequency distributions of the hourly concentrations of SO_2 during the exposure periods for the chamber and ambient treatments.

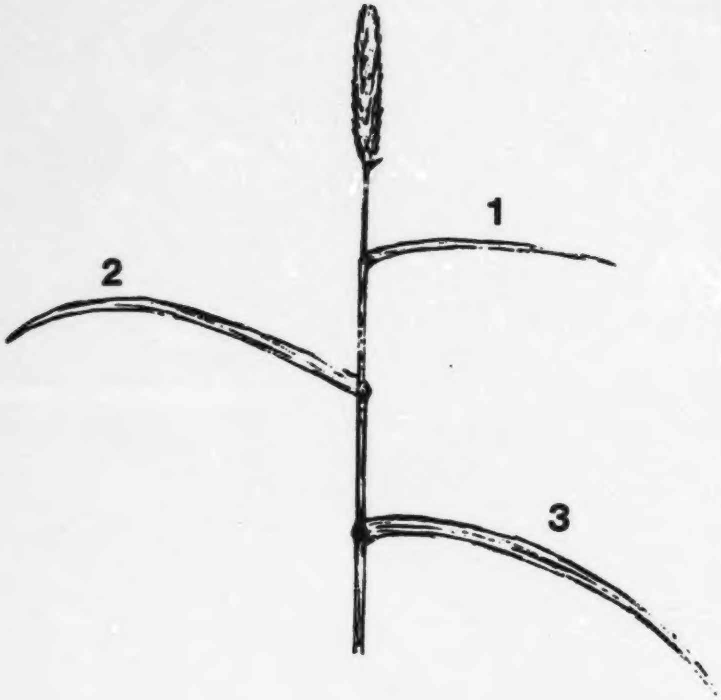

Figure 4.2.1.4. Illustration of a timothy culm and the numbering of the different leaf blades.

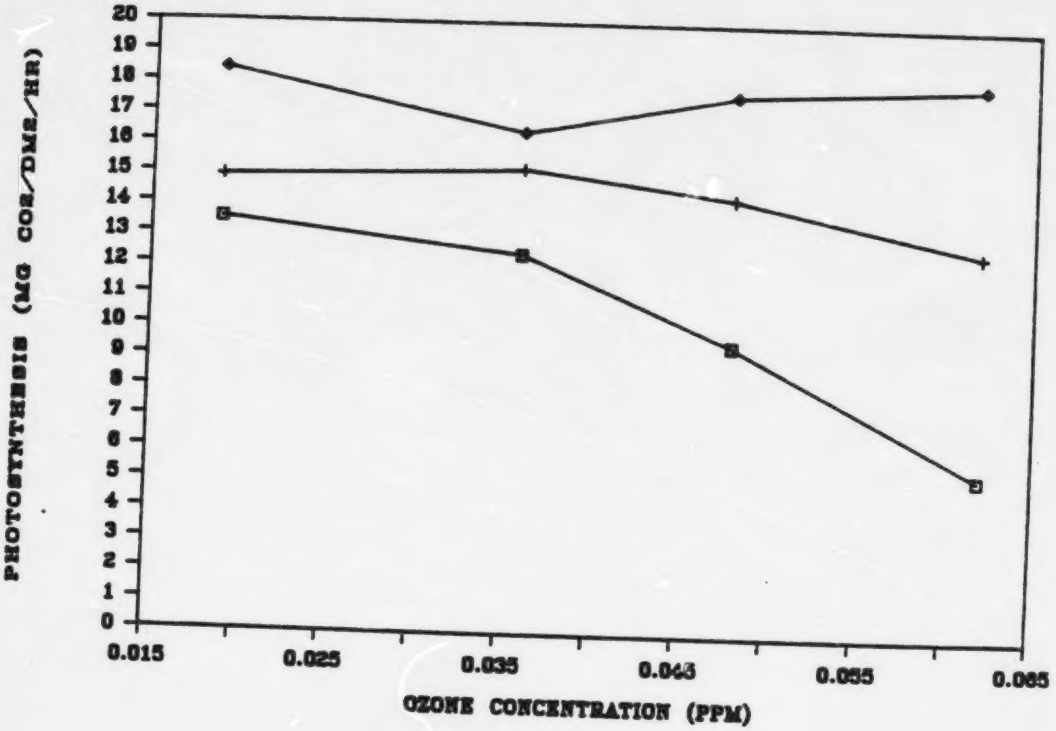

Figure 4.2.1.5. Effect of O_3 on photosynthesis of leaf blades 1 (◇), 2 (+), and 3 (□). Concentrations of O_3 are seasonal 12-hr means.

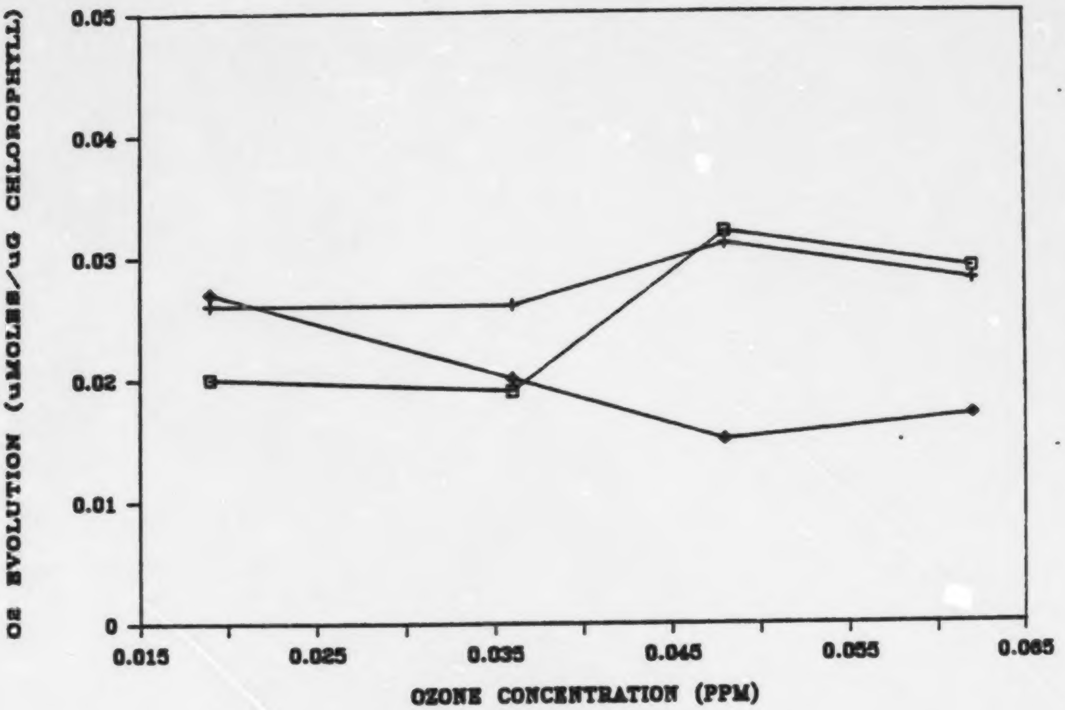

Figure 4.2.1.6. Effect of O_3 on O_2 evolution of leaf blades 1 (◇), 2 (+), and 3 (□). Concentrations of O_3 are seasonal 12-hr means.

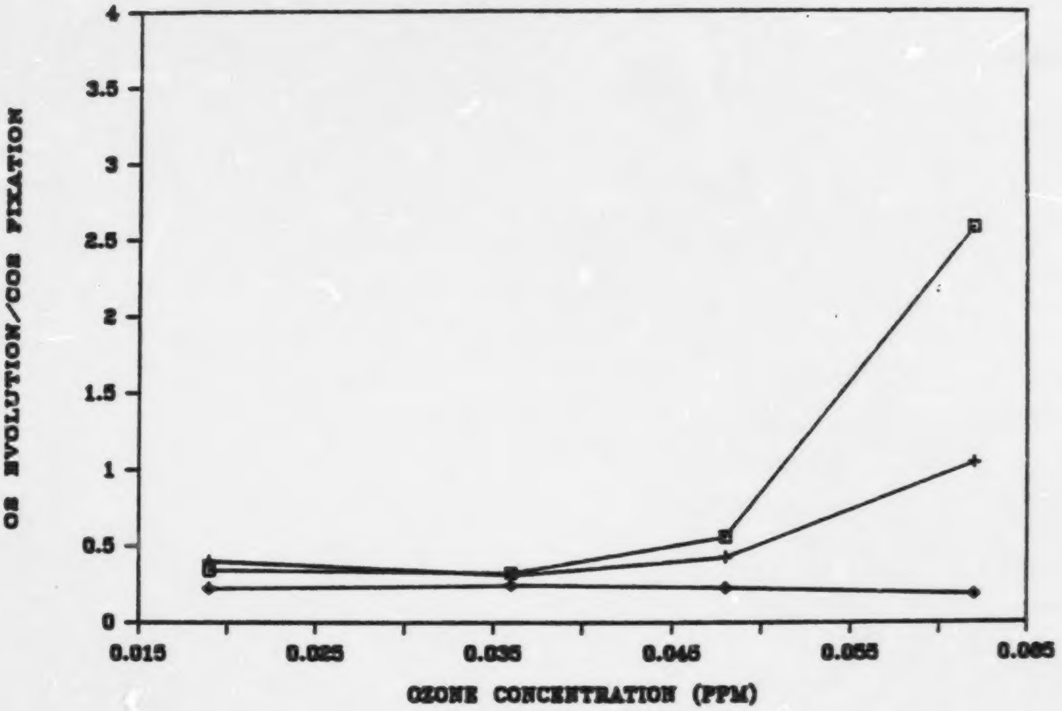

Figure 4.2.1.7. Effect of O_3 on the ratio of O_2 evolution to CO_2 fixation in leaf blades 1 (◇), 2 (+), and 3 (□). Concentrations of O_3 are seasonal 12-hr means.

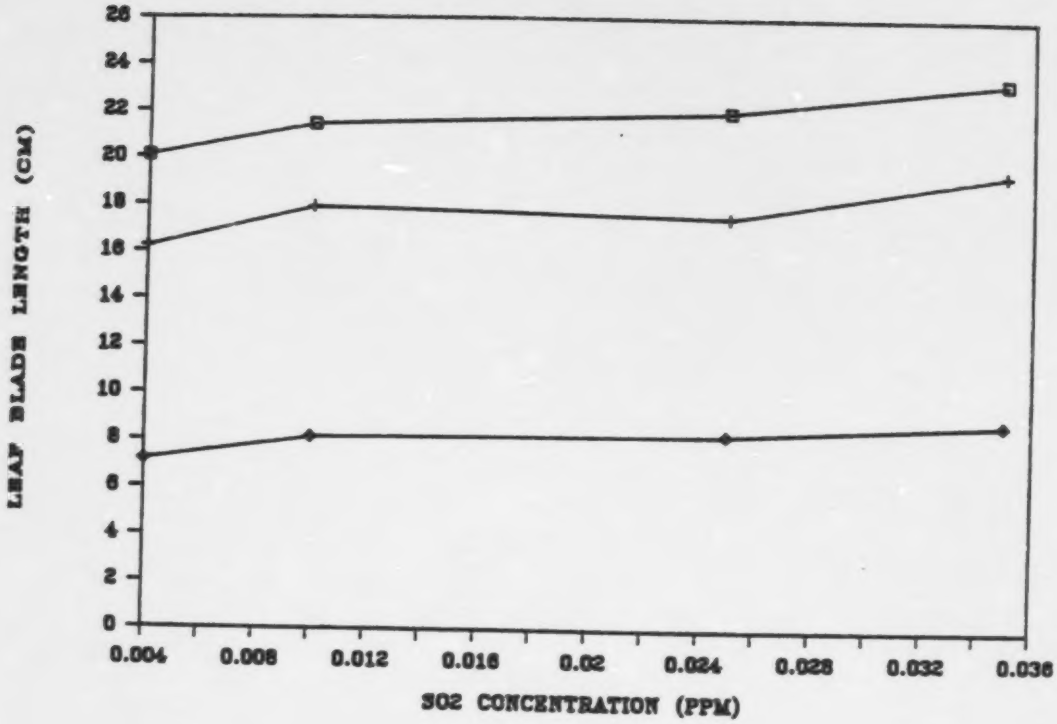

Figure 4.2.1.8. Effect of SO_2 on length of leaf blades 1 (◇), 2 (+), and 3 (□). Concentrations of O_3 are seasonal 12-hr means.

Dose-response. The total biomass obtained in each treatment from the two harvests is presented in Table 4.2.1.9. The allocation of the harvest biomass between timothy and red clover is presented in Tables 4.2.1.10. and 4.2.1.11., respectively. Analysis of variance indicated that neither O_3 nor SO_2 had any major effect on the yield of forage in 1985 (Table 4.2.1.12.). Regression analysis confirmed these results with very low r-square values. This lack of effect can be attributed to three factors operating in concert. First, the forage stand was in its second year and exhibited a high degree of heterogeneity in stocking and composition. Second, clover was declining in the stand as is expected in the second year of a clover/timothy mix. Third, timothy was more resistant to O_3 than was clover. Acting together, these factors resulted in a highly variable stand of forage that was dominated by an O_3-resistant species. Consequently, no statistically significant impacts of either pollutant were found on the forage crop in 1985.

Nutrient analysis. The nutrient and elemental contents of the timothy and red clover in the treatment harvests were compared to those of the plants harvested before treatments were initiated. None of the measures of nutritional value in either species were affected by the treatments. The concentrations of elements in the plant tissues were unchanged except for that of sulfur which, as anticipated, exhibited a minor increase with increasing treatment levels of SO_2.

4.2.1.4. Discussion

The assessment of the responses of the mixed forage crop of timothy and red clover to the SO_2 and O_3 exposures in the two years of the study was facilitated by the physiological studies. Because of the large number of treatments, physiological measurements were made on clover in the first year of the study and on timothy in the second year. Although the effects of the pollutant treatments were greater on clover than they were on timothy, there were several similarities in the responses. There were no measurable interactions between the two pollutants in affecting the rates of photosynthesis or growth of either of the species of forage. Exposure to SO_2 produced measurable reductions in photosynthesis of either species only at relatively high concentrations greater than 0.7 ppm. Ozone reduced CO_2 uptake and increased O_2 evolution in both species and produced greater effects in older tissues. These O_3-induced reductions in photosynthetic rates have been shown to be highly correlated to reductions in growth in crop and tree species (25).

The assessments of CO_2 uptake, O_2 evolution, and growth indicated that the O_3 treatments and the competition between clover and timothy acted to change the species composition and the productivity of the crop. Clover was found to be highly sensitive to O_3 while timothy was relatively resistant. These differences in susceptibility to O_3 reduced the amount of clover found in the high O_3 treatments and led to a reduction in biomass production.

The second year of the study was conducted on plots that had not previously been exposed to the pollutants. The amount of clover in a mixed forage stand is normally reduced in the second year by root

Table 4.2.1.8. Effect of SO_2 on O_2 evolution from leaf blades of timothy. Measurements were made 4 to 12 days before harvest 2.

SO_2 Treatment	O_2 Evolution (µmole/µg chlorophyll) Leaf Blade Number 1	 2	 3
Control	(12)[a] 0.021 ± .003	(48) 0.028 ± .002	(15) 0.024 ± .005
Low	(3) 0.017 ± .006	(25) 0.027 ± .003	(15) 0.025 ± .004
Medium	(0)	(36) 0.025 ± .002	(16) 0.026 ± .004
High	(0)	(35) 0.051 ± .005	(16) 0.064 ± .010

[a] ( ) Sample number.

Table 4.2.1.9. Total biomass of red clover and timothy harvested from open-top chambers in two harvests after pollutant treatments were initiated. Yields in kg/ha.

SO_2 Treatment (ppm)	O_3 Treatment (ppm) 0.019	 0.036	 0.048	 0.062	Mean
0.004	2259	1609	2229	1289	1846
0.010	1515	1554	1819	1456	1586
0.025	1409	1516	1267	1567	1440
0.035	1668	1698	1532	1448	1586
Mean	1713	1594	1711	1440	

Table 4.2.1.10. Total biomass of timothy harvested from open-top chambers in two harvests after pollutant treatments were initiated. Yields in kg/ha.

SO_2 Treatment (ppm)	O_3 Treatment (ppm)				Mean
	0.019	0.036	0.048	0.062	
0.004	880	1007	750	250	722
0.010	584	382	612	568	536
0.025	811	980	1083	1033	976
0.035	602	1256	952	810	905
Mean	719	906	849	655	

Table 4.2.1.11. Total biomass of red clover harvested from open-top chambers in two harvests after pollutant treatments were initiated. Yields in kg/ha.

SO_2 Treatment (ppm)	O_3 Treatment (ppm)				Mean
	0.019	0.036	0.048	0.062	
0.004	1380	602	1479	1039	1125
0.010	932	1172	1207	888	1049
0.025	599	537	185	534	463
0.035	1065	443	580	638	681
Mean	994	689	863	774	

Table 4.2.1.12. Analysis of variance for the effects of O_3 and SO_2 on the yield of red clover and timothy in the study conducted in Ithaca, NY in 1985.

Source of Variation	df	Mean Square Estimates[a/],[b/]						
		Timothy			Clover			
		1st Harvest	2nd Harvest	Total	1st Harvest	2nd Harvest	Total	Total Biomass
Block	1	2125.2	0.1	2103.4	4617.2	894.0**	9574.6	2702.7
O_3								
Linear	1	0.2	67.3	60.4	237.9	77.8	587.9	1025.1
Quadratic	1	1381.6*	0.3	1422.5	180.0	80.9^t	502.4	234.1
Cubic	1	8.0	40.6	12.5	1014.7	1.0	950.3	744.9
SO_2								
Linear	1	887.9	459.4	2624.8	5260.8	300.4	8075.7*	1492.4
Quadratic	1	24.4	50.6	4.7	1518.9	46.6	2047.9	1903.3
Cubic	1	1813.5	7.1	2047.7	1280.7	8.3	1494.7	43.4
O_3 x SO_2	9	340.6	47.8	533.3	822.4	28.5	743.8	728.2
O_3 x Block	3	59.3	37.5	183.5	438.6	70.7	679.9	871.9
SO_2 x Block	3	354.6	105.9	739.2	566.4	49.5	360.6	895.3
O_3 x SO_2 x Block	9	1562.4	102.4	1286.8	3865.8	70.4	4985.6	2242.6

[a/] All yields in $g/.5m^2$.

[b/] Significance levels: t = .10; * = .05; ** = .01.

pathogens and competition with other species in the community. The community dynamics of the species in the stand were enough, in some instances, to virtually eliminate clover from many of the plots. Because of the loss of clover from the stands and the low sensitivity of timothy to O_3, the O_3 treatments had no effect on stand productivity in the second year. Even though O_3 reduced photosynthetic rates and accelerated senescence in the older leaves of timothy, these effects were apparently offset in timothy by the reduced competition with clover. Thus, even though O_3 produced physiological effects in both species, the effects of the treatments on the productivity of the community were determined to a large extent by the interactions of the members of the community.

4.2.2. Impact of O_3 and SO_2 on Field Corn Hybrids (CSRCLAP)--L.W. Kress, P.M. Irving, and H.J. Smith

4.2.2.1. Introduction

Field corn (Zea mays L.) is the most important agricultural crop in the United States, and the major production areas are subjected to potentially damaging concentrations of O_3. A study completed in 1981 at Argonne was used to develop a model for the impact of O_3 on grain yield of field corn. A Weibull model predicted losses of 2.6 percent at 0.06 ppm O_3 and 16.3 percent at 0.10 ppm O_3 (7-hr seasonal mean) (9). The ambient O_3 concentrations throughout most of the Midwest are 0.04-0.06 ppm.

The present study was funded jointly by EPA and EPRI to determine 1) the exposure-response relationship between daily O_3 exposure and yield of four field corn hybrids; 2) the exposure-response relationship between simulated point source SO_2 exposure and yield of four field corn hybrids; and 3) the potential interaction of daily O_3 exposure and intermittent SO_2 exposure on the yield of the four corn hybrids.

4.2.2.2. Materials and Methods

Forty-four plots were planted on 22 May using a 76-cm row spacing with 1-meter (6 plants) of each of four hybrids in the two 2-m center rows of each plot. 'Pioneer 3780' was planted in the northwest quadrant in block A and in the southwest quadrant of block B. 'FR20A x FR634' was planted in the northeast quadrant of block A and in the southeast quadrant of block B. 'FR20A x FR35' was planted in the southwest quadrant of block A and in the northwest quadrant of block B. 'FR23 x LH74' was planted in the southeast quadrant of block A and in the northeast quadrant of block B. Border rows were planted on each side of the two center rows using mixed seed of the four hybrids. Many of the important events concerning the experiment are listed in Table 4.2.2.1. The soil for this study was a Morley silt loam (fine, illitic, mesic, Typic Hapludalf), and has been described in Table 4.1.3.3. Ambient rainfall for May-August was 77 percent (27.1 cm) of normal (35.1 cm).

The experimental design was a replicated split-plot with the whole-plot treatments being the factorial combinations of seven O_3 and three SO_2 pollutant concentrations and the sub-plot treatments being the four corn hybrids. The O_3 treatments were charcoal-filtered (CF), nonfiltered (NF), 1.33 NF, 1.67 NF, 2.0 NF, 2.5 NF, and 3.5 NF. There also was a nonchambered plot (AA) in each block. Open-top chambers were established over the plots on 10 June, and proportional O_3 additions were performed whenever ambient O_3 was above 0.03 ppm during a 0700-1900 CST window from 16 June to 5 September, 1985. The average length of the daily exposures was 9.4 hours for 80 days when O_3 was actually dispensed during the 82-day exposure period (Table 4.2.2.2.). Ozone was not added on two days due to low ambient O_3, and exposures were terminated at 1500 on four days due to rain. Generator malfunction caused the loss of 1.25 hours.

The SO_2 treatments were zero (ambient), medium-frequency distribution, and high-frequency distribution. The SO_2 exposures

Table 4.2.2.1. Chronology of activities during the experiment to determine the effects of O_3 and/or SO_2 on four field corn hybrids at Argonne, IL.

Month	Day	Event
May	11	Fertilizer applied - (N-P-K) - 246-64-64 kg/ha
	20	Chamber frames in place
	22	Planted corn seed - 76-cm row spacing - seeds 18 cm apart - 1 m/hybrid/plot
	23	Watered corn plots with a lawn sprinkler
	29	Plants emerging
June	5	Top plastic panels installed
	9-10	Bottom panels installed - fans on - no CF filters
	15	Charcoal filters installed
	16	Initiate proportional O_3 additions - plants 10 cm tall
	19	Thinned corn plants - 6 plants/m
July	1	Initiate intermittent SO_2 exposures
August	2	Pollen shed beginning
	12	Sevin applied for greenbug/aphid control (22 ml/3.785 L) - total of 44.4 liters applied on 44 plots
	23	Independent instrument audit
	31	Dent and black line forming in corn grain indicating physiological maturity - AA, CF, and 3.5 NF plots
September	5	Last O_3 addition day
	15 to	Harvest the two center rows (1 m for each hybrid) of each plot as corn husks turned brown and dry
October	14	

Table 4.2.2.2. Summary of O_3 addition start and stop times, exposure length, average O_3 concentration at exposure termination, and number of days for various exposure lengths during 82 days for the experiment to determine the effects of O_3 on four field corn hybrids at Argonne, IL.

Date	Avg. Start Time	Avg. Stop Time	Avg. Length (hrs)	Avg. Amb. Conc. at Stop Time (ppm)	Number of Days Exposures Were		
					12 hrs	> 10 hrs	< 8 hrs[a]
June 16-30	0908	1957	10.8	.043	5	11	0
July 1-31	0919	1917	9.9	.054	5	18	5
August 1-31	1054	1914	8.3	.034	0	8	10
September 1-5	1048	1957	9.2	.035	0	2	2

[a] There were no O_3 additions on July 30 and 31 due to low ambient O_3. Exposures were terminated at 1500 on four days due to rain.

simulated the concentration, duration, and frequency dynamics associated with point sources. Ambient monitoring data obtained from the Tennessee Valley Authority were used to develop the SO_2 treatments (Kohut et al., Section 4.2.1., this report). The SO_2 exposures began on 1 July and differed not only in the hourly concentrations, but also in the total hours of exposure (75 hours for the medium and 143 for the high treatments). Exposures lasting 4 to 6 hr occurred two or three times per week in the high treatment (total of 26 exposures). Exposures lasting 3 to 5 hr occurred one or two times per week in the medium treatment (total of 19 exposures).

Each plot was sampled for O_3 concentration (Bendix Model 8002 Chemiluminescent) and SO_2 concentration (Meloy SA285 Flame Photometric) for 2 min out of every 20 or 22 min. Ozone instruments were calibrated weekly with a CSI Photocal 3000 and SO_2 instruments were calibrated with a CSI 1700 Gas Phase Titration Unit and an NBS traceable bottled SO_2 source. The O_3 values were adjusted for sampling system losses (7-13%) for each plot.

Ambient O_3 and SO_2 were monitored continuously at a 3-meter height with Bendix 8002 Chemiluminescent and TECO 43 Pusled Fluorescent analyzers, respectively.

All treatment plots were surveyed on 30 July to determine average plot height and stage of development for each of the four hybrids. In mid-August, plots were reevaluated to determine ear development and height to ear.

Foliar injury was evaluated on the ear leaf of one plant of each hybrid in each plot on 2 September. Injury was estimated as percent chlorotic streak, percent necrosis, and percent general chlorosis (intervals of 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90 percent).

The plants were sampled in late July and late August to determine chlorophyll content of six leaf disks removed from the middle portion of the ear leaf. Chlorophyll was extracted with ethanol and absorbance was measured spectrophotometrically and converted to chlorophyll content according to Knudson et al. (22). Photosynthetic rates of the ear leaf were determined for one plant per hybrid per plot in early August for hybrids 3780 and FR20A x FR35 and in late August for hybrids FR20A x 634 and FR23 x LH74. A LiCor 6000 photosynthesis apparatus which measures carbon dioxide and water vapor exchange was used for the measurements.

Soil respiration, which quantified net heterotrophic activity of the soil (bacterial, fungal, faunal, and root), was determined by measuring carbon dioxide evolution from the soil surface for a 24-hr period, according to a method described by Stotzky (23). Soil respiration rates were measured near the center of each plot and thus represent the average effect on all four hybrids. Measurements were made in early August and early September.

Following exposure termination on 5 September, measurements were made of plant height, stem circumference just above the uppermost support roots, and number of cobs with kernels/plant. Following the individual plot harvests (as the husks turned brown and dried - 15 September to 14 October) the ears were dried and shelled. Weights of grain and cob, cob length, and length of cob with kernels were recorded. Weight of 100 seeds was also recorded. Seed weight/m row was adjusted to reflect 15.5 percent moisture content and converted to kg/ha. Soil samples collected after harvest were sent to the Soil and Plant Analysis Laboratory, University of Wisconsin, for analysis of pH, organic matter, P, and K.

The chamber plot data were analyzed by a split-plot analysis of variance. The sources of variation were block, O_3 treatment, SO_2 treatment, O_3 x SO_2, block x O_3 x SO_2 (error a), hybrid, hybrid x O_3, hybrid x SO_2, hybrid x O_3 x SO_2, and residual (error b). The analyses were also run for each hybrid, each O_3 treatment, and each SO_2 treatment separately. Linear, quadratic, and Weibull models were developed for the O_3 and SO_2 effects for each hybrid and the combined data.

4.2.2.3. Results

Pollutant concentrations. The daily 1-hr peak and 12-hr mean ambient O_3 concentrations were lower in 1985 than in the past few years, especially for August (even though rainfall was well below normal in August) (Figure 4.2.2.1.). The highest 1-hr value during earfill (mid- to late August) was 0.081 ppm on 8 August and there were only 5 days when the ambient O_3 was above 0.07 ppm.

The mean seasonal O_3 concentrations (12-hr/day) for the eight O_3 treatments were 0.045 ppm, 0.016 ppm, 0.042 ppm, 0.056 ppm, 0.069 ppm, 0.082 ppm, 0.101 ppm, and 0.126 ppm for the AA, CF, NF, 1.33 NF, 1.67 NF, 2.0 NF, 2.5 NF, and 3.5 NF treatments, respectively. The highest and second highest 12-hr mean and 1-hr peak values have also been provided in Table 4.2.2.3. The mean seasonal hourly average diurnal fluctuations in O_3 concentrations for all O_3 treatments are shown in Figure 4.2.2.2.

Sulfur dioxide was added to simulate a point source (Table 4.2.2.4.). The high frequency treatment was exposed for 143 hours on 26 days to a total dose of 19.6 ppm-hr during a 7-hr (0800-1500 CST) window (1.86 ppm-hr of which was from ambient exposures during non-fumigation hours). The medium frequency treatment was exposed for 75 hours on 19 days to a total dose of 9.69 ppm-hr (2.24 ppm-hr from ambient). The total dose during the 7-h exposure window in the zero (or control) treatment was 2.8 ppm-hr over a 67 day period (469 hr) between 1 July and 5 September. The highest hourly average concentration in the high treatment was 0.75 ppm, in the medium was 0.45 ppm, and in the control (ambient) was 0.068 ppm. The highest instantaneous peak in ambient was 0.104 ppm.

Foliar injury. Foliar injury was noted, primarily in the form of chlorotic streak similar to magnesium deficiency in corn (Table 4.2.2.5.). There was some necrosis, but it exceeded 6 percent only in the highest O_3 treatment for 'FR20A x FR35 (18 percent). While the amount of injury did generally increase with increasing severity of pollutant treatment, the amount of injury did not always correlate directly with yield reductions.

Table 4.2.2.3. Seasonal mean 12-hr/day and 1-hr/day peak O_3 concentrations and the highest and second highest values of each measure, for each treatment during the 0700-1900 CST exposure window for the experiment to determine the effects of O_3 on four field corn hybrids at Argonne, IL.

	12-hr/day Values (ppm)[a/]			1-hr/day Peak Values (ppm)[b/]		
Treatment	Seasonal Mean	Highest	Second Highest	Seasonal Mean	Highest	Second Highest
AA	0.045	0.084	0.076	0.062	0.103	0.101
CF	0.016	0.051	0.050	0.025	0.072	0.068
NF	0.042	0.085	0.075	0.060	0.105	0.096
1.33 NF	0.056	0.118	0.094	0.079	0.153	0.136
1.67 NF	0.069	0.138	0.112	0.099	0.176	0.158
2.0 NF	0.082	0.166	0.151	0.120	0.222	0.205
2.5 NF	0.101	0.201	0.193	0.151	0.272	0.263
3.5 NF	0.126	0.246	0.223	0.194	0.353	0.305

[a/] Mean values are the average of six plots with hourly averages generated from 2-3 2-minute readings per hour. Highest and second highest values are from one of the six replicates.

[b/] Values from one open plot.

Table 4.2.2.4. Concentrations and number of hours of SO_2 exposure in the experiment to determine the effects of SO_2 and O_3 plus SO_2 on four field corn hybrids at Argonne, IL.

Concentration (ppm)	Number of Hours of Exposure[a]	
	High Frequency[b]	Medium Frequency[c]
0.00	326	394
0.05	84	47
0.10	22	12
0.15	14	7
0.20	7	1
0.25	2	3
0.30	1	1
0.35	3	1
0.40	1	2
0.45	2	1
0.50	1	0
0.55	1	0
0.60	1	0
0.65	1	0
0.70	2	0
0.75	1	0

[a] Total of 469 hours between 0800-1500 CST, 1 July to 4 September, 1985.

[b] SO_2 exposures were run for 4-6 hours between 0800-1500 CST on 26 days for a total of 143 exposure hours. The 0.00 hours were ambient exposure (1.86 ppm-hrs). Total dose was 19.36 ppm-hrs.

[c] SO_2 exposures were run for 3-5 hours between 0800-1400 CST on 19 days for a total of 75 exposure hours. The 0.00 hours were ambient exposure (2.24 ppm-hrs). Total dose was 9.69 ppm-hrs. The control dose was 2.86 ppm-hrs.

Table 4.2.2.5. Percent foliar injury on the ear leaves of four corn hybrids exposed to O_3 and/or SO_2 at Argonne, IL.

Treatment	Percent foliar injury (mean of all SO_2 treatments)			
	Pioneer 3780	FR20A x FR634	FR20A x FR35	FR23 x LH74
	Str - Nec - Chl[a]	Str - Nec - Chl	Str - Nec - Chl	Str - Nec - Chl
AA	0 - 1 - 3	0 - 0 - 0	8 - 1 - 1	0 - 1 - 1
CF	0 - 1 - 1	0 - 1 - 0	0 - 0 - 1	0 - 1 - 1
NF	0 - 1 - 2	2 - 1 - 0	0 - 0 - 3	1 - 1 - 2
1.33 NF	0 - 1 - 3	8 - 1 - 5	2 - 0 - 3	5 - 1 - 9
1.67 NF	4 - 1 - 12	19 - 6 - 32	19 - 0 - 8	14 - 2 - 8
2.0 NF	5 - 1 - 11	8 - 1 - 23	40 - 4 - 3	14 - 1 - 1
2.5 NF	31 - 4 - 0	35 - 2 - 0	50 - 6 - 0	23 - 2 - 0
3.5 NF	35 - 5 - 9	25 - 5 - 5	52 - 18 - 5	28 - 4 - 2
	Percent foliar injury (mean of all O_3 treatments)			
Control	6 - 2 - 4	11 - 1 - 7	19 - 2 - 3	9 - 1 - 2
Medium	12 - 2 - 7	13 - 3 - 7	23 - 5 - 3	12 - 2 - 1
High	13 - 2 - 4	16 - 2 - 13	26 - 6 - 4	15 - 2 - 6

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[a] Str = chlorotic streak between the veins. Nec = necrotic patches. Chl = generalized chlorosis, including veins.

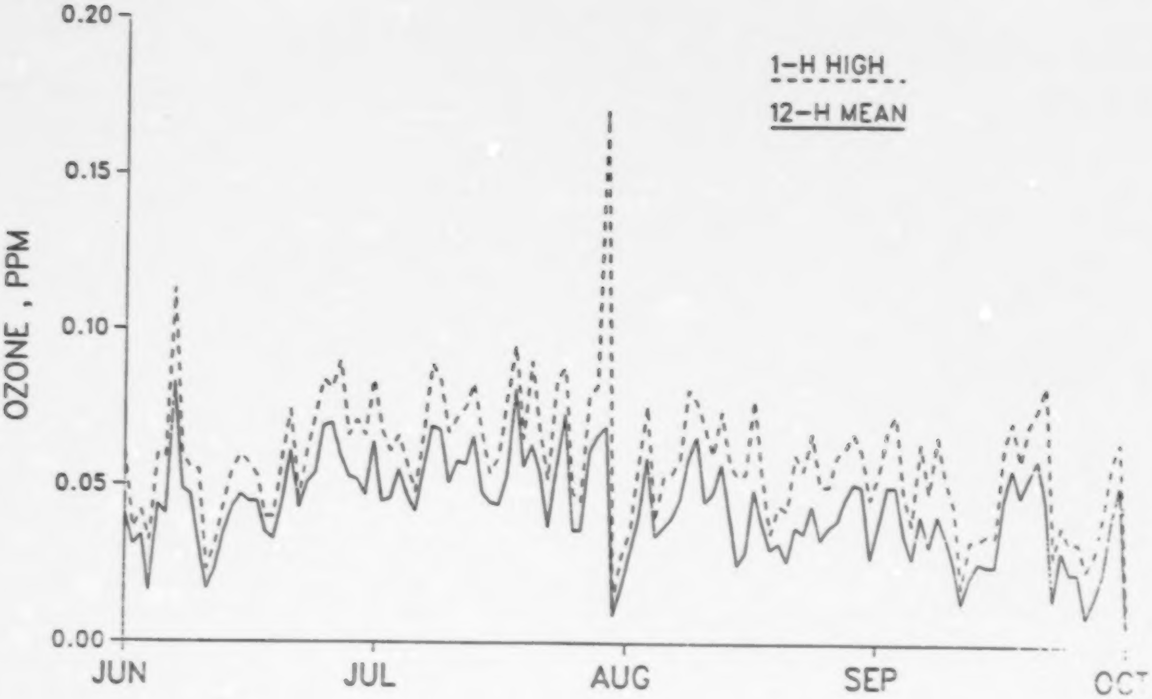

Figure 4.2.2.1. Ambient O_3 data collected from 1 June to 30 September 1985, showing daily 1-hr high and daily 12-hr mean (0700-1900 CST). Experimental treatments ran from 16 June - 5 September.

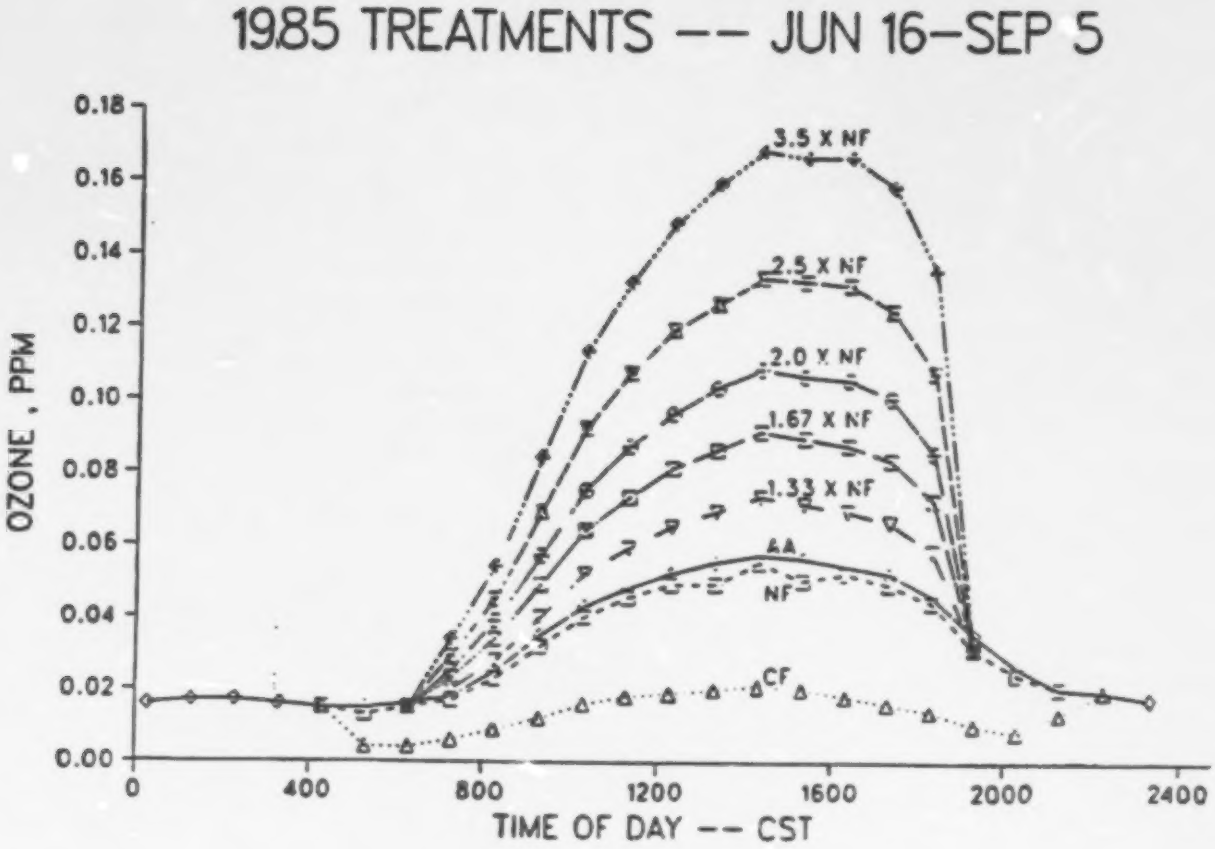

Figure 4.2.2.2. Diurnal pattern of mean hourly O_3 concentrations in ambient air (AA), charcoal-filtered air chambers (CF), or in non-filtered chambers (NF) with various amounts of O_3 added from 0700-1900 CST 16 June to 5 September 1985. All chamber fans were turned off nightly from 2130 to 0530 CST.

For hybrid 'FR20A x FR634' as the O_3 treatment went from 1.67 NF to 2.0 NF the foliar injury went from 25 to 9 percent while the yield reduction went from 15 to 20 percent.

Physiology. The highest O_3 treatment suppressed the number of developing ears per plant in hybrid FR23 x LH74 ($p = 0.002$). Sulfur dioxide at the highest exposure level suppressed the number of ear initials per plant in hybrid FR20A x FR634 ($p = 0.009$); plant height to ear was also reduced by SO_2 for this hybrid ($p = 0.01$).

Leaf chlorophyll concentrations in all hybrids were reduced by O_3 treatments above 0.07 ppm when measured in late August ($p = 0.0001$) (Figure 4.2.2.3.). No differences in leaf chlorophyll content were observed among O_3 treatment groups for plants sampled in late July. Both chlorophyll-a and chlorophyll-b were reduced by O_3, however chlorophyll-a was reduced to a greater extent than chlorophyll-b in all but hybrid FR20A x FR35. Sulfur dioxide affected total chlorophyll content (chl-a plus chl-b) only in hybrid FR20A x FR634 ($p = 0.05$) and there were no interactive effects of O_3 and SO_2 for any hybrids. According to the chlorophyll data, hybrid Pioneer 3780 is less sensitive to O_3 than the other three hybrids. The chlorophyll data also indicated a chamber effect. Plants growing in the NF open-top chambers appeared to have reduced levels of chlorophyll-a and increased levels of chlorophyll-b compared to ambient air plots. The ratio of chlorophyll-a to chlorophyll-b was approximately 3.5 : 1 in the NF plots and 2.4 : 1 in the ambient air plots. The effect could be due to differences in plant maturity between chambered and ambient plots. Physiological maturity appeared to occur sooner and develop more rapidly in the ambient air plots.

According to analysis of variance, there was a significant O_3, and hybrid x O_3 effect on photosynthetic rates of the corn. Ozone suppressed photosynthetic rates in all hybrids but Pioneer 3780 (Figures 4.2.2.4. and 4.2.2.5.). The lack of response for the Pioneer hybrid is consistent with the chlorophyll results. The presence and quantity of SO_2 influenced the response. The O_3 effect on photosynthetic rate was greatest for the two hybrids sampled in late August (Figure 4.2.2.4.) compared to those sampled in early August (Figure 4.2.2.5.). This suggests that O_3 damage to photosynthetic processes is cumulative and that field corn is tolerant to low doses of O_3.

The measurements of soil respiration in early August indicated that reduction in the net heterotrophic activity of the soil was associated with increased O_3 concentrations (Figure 4.2.2.6.). According to analysis of variance, this effect was not statistically significant ($p = .097$). The SO_2 exposures had no effect on the rates of respiration at that time and there were no interactive effects. Respiration rates in the ambient plots were more than 40% greater than those in the chambered plots, probably because senescence was at an earlier stage in the ambient plots. Respiration measurements completed in early September, when plants were in later stages of senescence, indicated that the rates had fallen to nearly zero and that there was no significant effect of the O_3 at this time. However, rates in the plots treated with the highest SO_2 exposures were

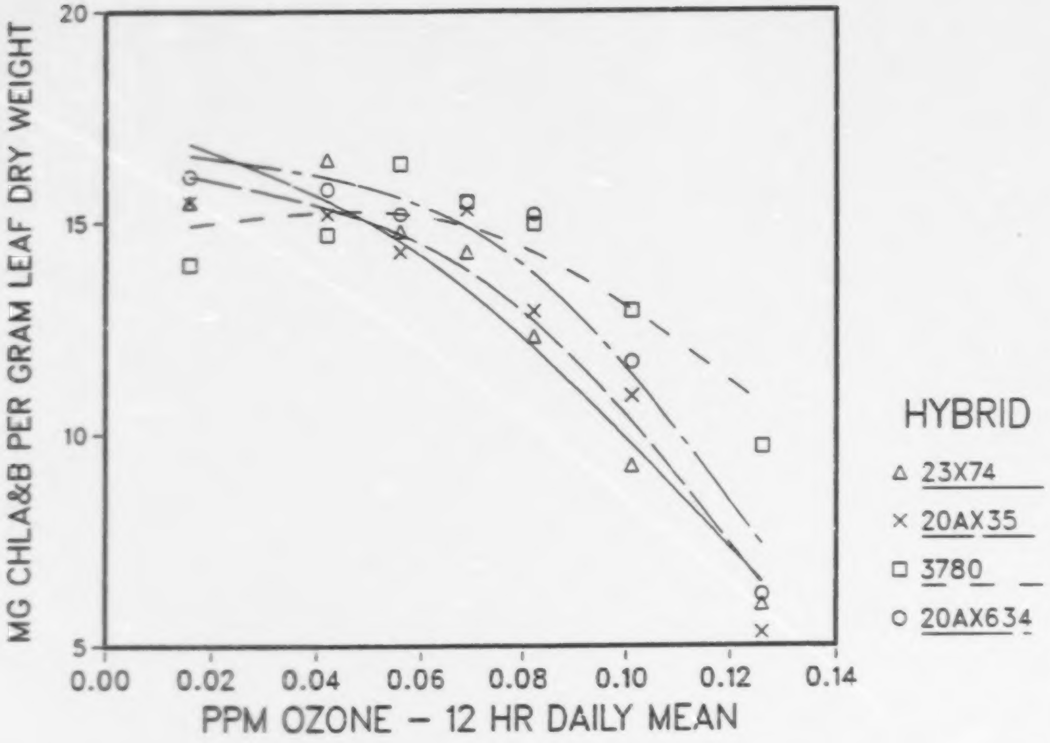

Figure 4.2.2.3. Average chlorophyll concentrations of the ear leaf from four hybrids of field corn as a function of O_3 concentration across the three SO_2 concentrations.

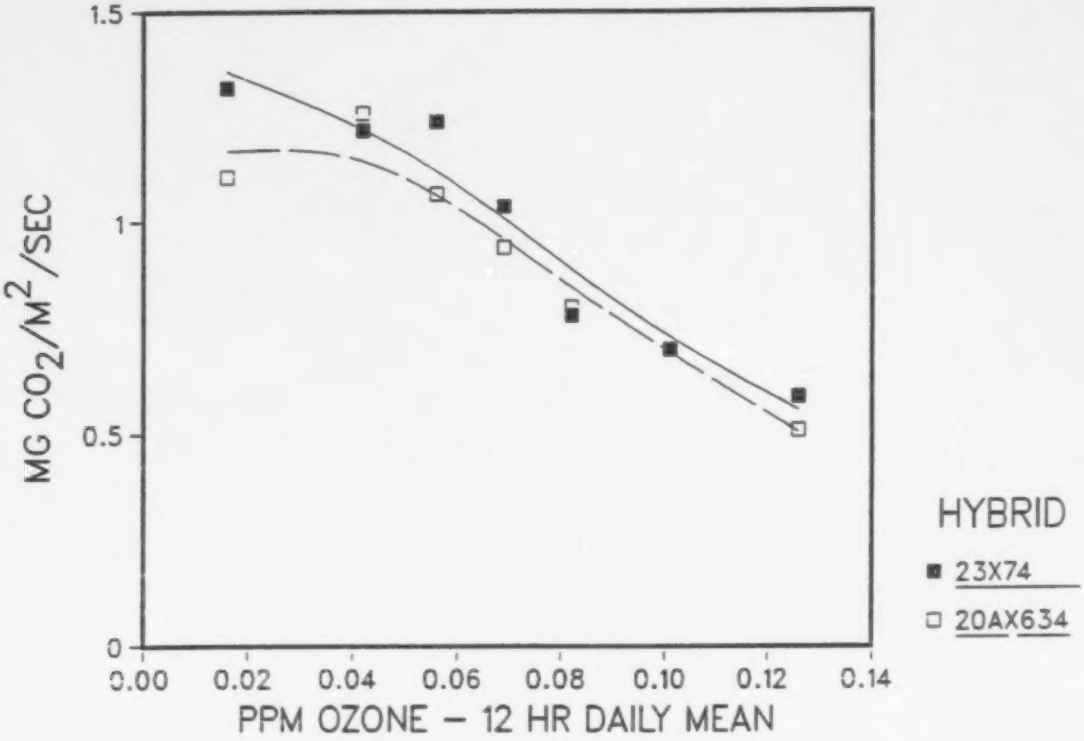

Figure 4.2.2.4. Photosynthetic rate of the ear leaf from two hybrids of field corn as a function of O_3 concentration across three SO_2 concentrations. The measurements were made in late August, 1985.

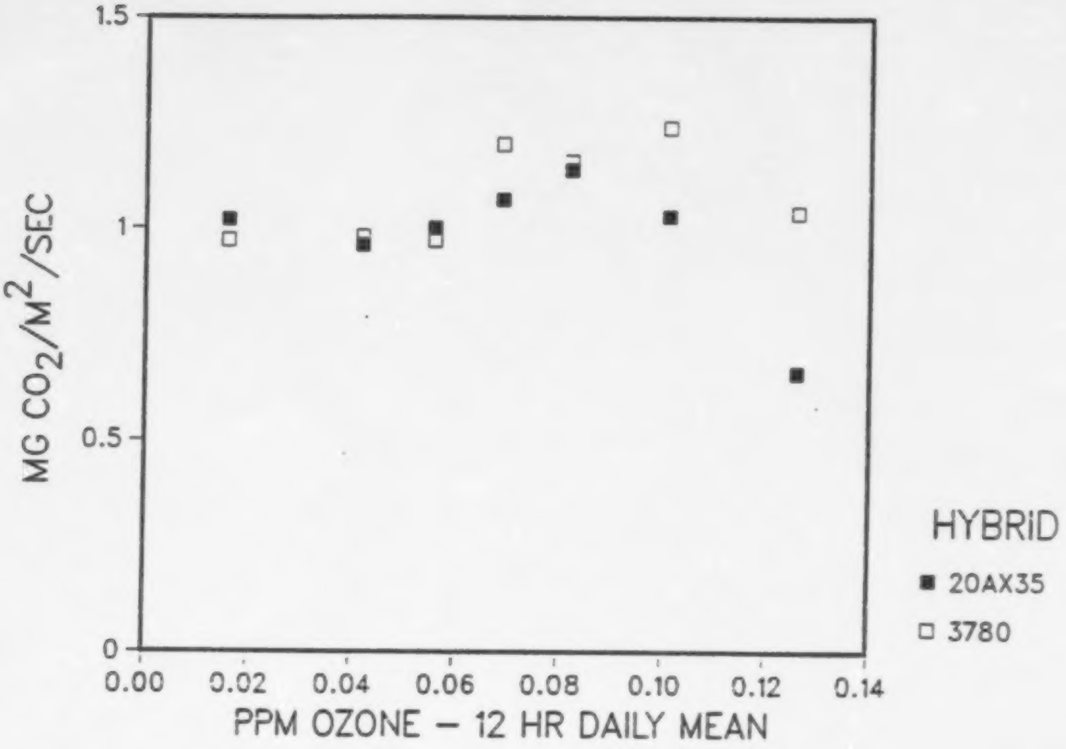

Figure 4.2.2.5. Photosynthetic rate of the ear leaf from two hybrids of field corn as a function of O_3 concentration across the three SO_2 concentrations. The measurements were made in early August, 1985.

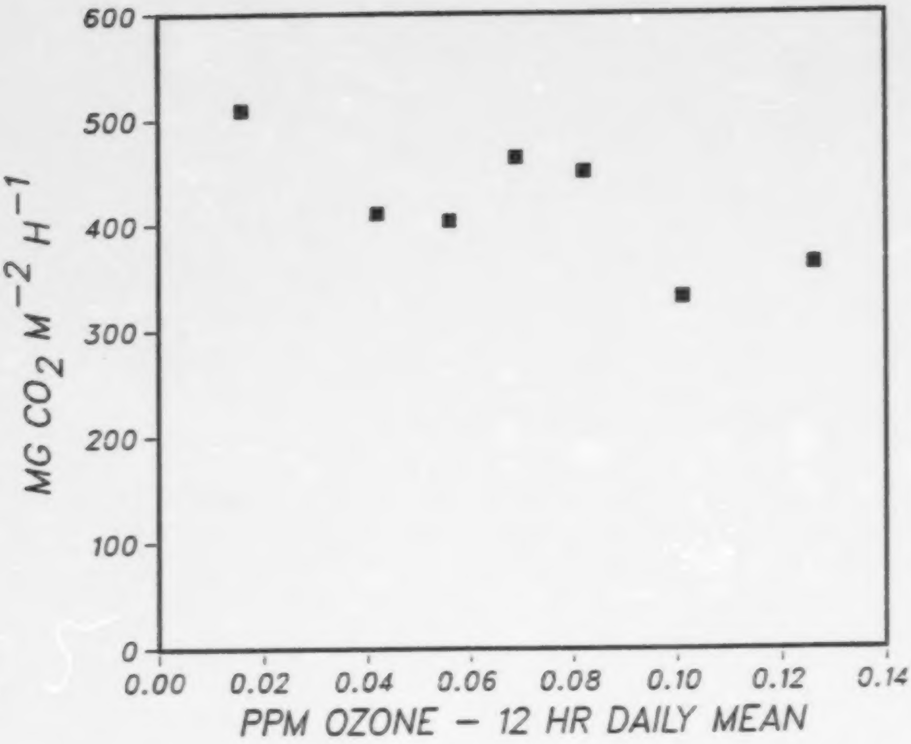

Figure 4.2.2.6. Soil respiration measured in early August in corn plots as a function of O_3 concentration across all SO_2 treatments.

greater than the other plots (Figure 4.2.2.7.), although the results were not statistically significant because of the great amount of variability in the data.

Yield. The split-plot analysis of variance of the chamber plot data indicated significant ($p = 0.001$) O_3 effects on overall yield (kg/ha), weight of 100 seeds, number of seeds per meter, cob length, cob weight, percent of cob with kernels, stem circumference, and plant height ($p = 0.01$) (Table 4.2.2.6.). Significant hybrid effects were indicated for all of the above variables plus sparse kernel development (earsp) ($p = 0.001$), and number of ears per plant (earno) ($p = 0.05$). Ozone x hybrid effects for weight of 100 seeds ($p = 0.001$), cob weight and percent of cob with kernels ($p = 0.05$) were also significant. There was a significant ($p = 0.05$) SO_2 effect on percent of cob with kernels and an SO_2 x hybrid effect on sparse kernel development. There were also some significant block effects on weight of 100 seeds and plant height, as well as the soil variables of pH, organic matter, and phosphorus. The O_3 x SO_2 interaction effects were not significant ($p = 0.05$).

The grain yields of the four hybrids in response to O_3 treatment are shown in Table 4.2.2.7. Only one hybrid (FR20A x FR634) demonstrated a small increase in overall yield at near ambient concentrations. One hybrid (FR20A x FR35) appeared appreciably more sensitive to O_3 than the other three hybrids at the higher O_3 treatment concentrations.

A summary of the O_3 and SO_2 effects across all four hybrids indicated considerable response to O_3 and almost no response to SO_2 (Table 4.2.2.8.). There was an indication of increased O_3 sensitivity at the intermediate SO_2 treatment compared to both the control and the high treatment.

A quadratic regression model run for the yield response of corn averaged over all four hybrids indicated significant O_3, $(O_3)^2$, and O_3 x SO_2 components to the model with an R^2 of 0.76. A test for heterogeneity from "full" and "reduced" models indicated the hybrid responses were significantly ($p = 0.05$) different. There were no differences in response to O_3 at the various SO_2 treatment levels, but highly significant ($p = 0.01$) differences in response to SO_2 at the various O_3 treatment levels. The nature of the O_3 x SO_2 interaction suggested that SO_2 increased yields at low O_3 concentrations and decreased yields at higher (2.0, 2.5, and 3.5 x NF) O_3 concentrations. When the model was run for each hybrid separately, there was no significant O_3 x SO_2 component for an individual hybrid.

Weibull response models provided better fits to the data (Table 4.2.2.9. and Figure 4.2.2.8.). A common O_3 response model was adequate to describe the response of all four hybrids at the control and the highest SO_2 treatments. However, at the intermediate SO_2 treatment (9.69 ppm/hrs) and averaged over all SO_2 treatments there was significant hybrid variability in response to O_3. One hybrid (FR20A x FR35) appeared to change its O_3 response in response to changing SO_2 treatment. Greater changes occur in sigma and c (as well as alpha) and the results of these changes are shown in Figure 4.2.2.9.

Table 4.2.2.6. Results of split-plot analysis of variance of data from the experiment to determine the effects of O_3 and/or SO_2 on four field corn hybrids at Argonne, IL.

Source	df	Mean Square									
		Kg/ha[a/]	s100wt	snum	cobl	cobw	pctf	cir	ht	earsp	earno
Block	1	3	49**	3	4	7	2	108	278*	1	0
O_3	6	1757***	336***	344***	695***	259***	647***	267***	212***	5	8
SO_2	2	5	2	10	2	6	179*	3	12	9	18
O_3 x SO_2	12	45	4	28	16	11	37	36	80	2	6
O_3 x SO_2 x Block (error a)	20	29	4	16	15	11	39	37***	52***	3	6
Hyb	3	263***	280***	112***	455***	137***	873***	730***	1462***	16***	28*
O_3 x Hyb	18	39	20**	17	18	20*	60*	14	12	1	5
SO_2 x Hyb	6	13	2	7	7	6	38	5	8	4*	3
O_3 x SO_2 x Hyb	36	20	4	9	15	8	24	7	12	3	7
Residual	63	23	4	15	15	10	32	9	10	2	9

[a/] Kg/ha = Kilograms/hectare (mean square ÷ 100,000).
s100wt = weight of 100 seeds.
snum = number of seeds/meter (mean square ÷ 10,000).
cobl = cob length (mean square x 10).
cobw = cob weight.
pctf = percent of cob with kernels.
cir = stem circumference (mean square x 100).
ht = plant height (mean square x 1000).
earsp = sparse kernel occurrence along cob (mean square x 10).
earno = number of developed ears/plant (mean square x 100).
*, **, *** = p=0.05, 0.01, and 0.001, respectively.

Table 4.2.2.7. Grain yield of four field corn hybrids exposed to O_3 and/or SO_2 in open-top chambers at Argonne, IL. Yields are averaged across all SO_2 treatments.

O_3 Treatment	12-hr Seasonal Mean Concentration (ppm)	Grain Yield in ka/ha (± % of change from CF)			
		Pioneer 3780	FR20A x FR634	FR20A x FR35	FR23 x LH74
AA	0.045	10184 (-9.8%)	13041 (+4.0%)	9338 (-25.7%)	10953 (-7.4%)
CF	0.016	11287	13584	12567	11830
NF	0.042	10811 (-4.2%)	13923 (+2.5%)	11996 (-4.5%)	11794 (-0.3%)
1.33 NF	0.056	11108 (-1.6%)	13817 (+1.7%)	11859 (-5.6%)	11116 (-6.0%)
1.67 NF	0.069	10146 (-10.1%)	11589 (-14.7%)	10730 (-14.6%)	10989 (-7.1%)
2.0 NF	0.082	8896 (-21.2%)	10932 (-19.5%)	7656 (-39.1%)	9566 (-19.1%)
2.5 NF	0.101	8228 (-27.1%)	7923 (-41.7%)	6901 (-45.1%)	8730 (-26.2%)
3.5 NF	0.126	5273 (-53.3%)	5423 (-61.1%)	3480 (-72.3%)	5969 (-49.5%)

Table 4.2.2.8. Grain yield (average of four hybrids) of field corn exposed to O_3 and/or SO_2 in open-top chambers at Argonne, IL.

O_3 Treatment	12-hr Seasonal Mean Concentration (ppm)	Grain Yield in ka/ha (± % of change from CF)			
		SO_2 dose - (ppm hrs)			
		2.86	9.69	19.46	Average
AA	0.045	10879 (-5.3%)	----------	----------	----------
CF	0.016	11485	13348	12119	12317
NF	0.042	11124 (-3.1%)	12420 (-7.0%)	12849 (+6.0%)	12131 (-1.5%)
1.33 NF	0.056	12494 (+8.8%)	11122 (-16.7%)	12309 (+1.6%)	11975 (-2.8%)
1.67 NF	0.069	11044 (-3.8%)	11003 (-17.6%)	10543 (-13.0%)	10864 (-11.8%)
2.0 NF	0.082	10045 (-12.5%)	8795 (-34.1%)	8948 (-26.2%)	9263 (-24.8%)
2.5 NF	0.101	8166 (-28.9%)	8038 (-39.8%)	7632 (-37.0%)	7946 (-35.5%)
3.5 NF	0.126	5886 (-48.8%)	4603 (-65.5%)	4619 (-61.9%)	5036 (-59.1%)
Average	10035	9904	9860		

Table 4.2.2.9. Weibull model parameters (and 1 standard error) for the effect of O_3 treatment (12-hr mean) on yield of four field corn hybrids.

Hybrid	Parameter	SO_2 treatment - ppm-hr			
		2.86	9.69*	19.46	Average**
Pioneer 3780	alpha	10772 (802)	12363 (1157)	11378 (880)	11241 (478)
	sigma	0.145 (0.021)	0.151 (0.021)	0.128 (0.010)	0.138 (0.008)
	c	3.705 (2.292)	2.014 (0.926)	3.281 (1.279)	3.314 (0.880)
FR20Ax FR634	alpha	12998 (757)	12726 (926)	14780 (989)	14118 (510)
	sigma	0.132 (0.009)	0.124 (0.007)	0.119 (0.007)	0.126 (0.004)
	c	4.194 (1.680)	2.792 (0.762)	2.851 (0.764)	3.100 (0.533)
FR20Ax FR35	alpha	12116 (806)	15156 (1296)	12394 (1012)	12777 (542)
	sigma	0.121 (0.007)	0.103 (0.007)	0.117 (0.008)	0.115 (0.004)
	c	3.895 (1.325)	1.945 (0.478)	2.775 (0.881)	2.929 (0.492)
FR23x LH74	alpha	11036 (687)	11735 (867)	12892 (968)	11894 (490)
	sigma	0.139 (0.014)	0.145 (0.016)	0.137 (0.013)	0.142 (0.009)
	c	4.913 (2.988)	2.914 (1.341)	2.812 (1.104)	3.171 (0.844)
R^2 a/		0.82	0.94 0.96	0.98	
Average b/	sigma	0.134 (0.006)	0.128 (0.006)	0.125 (0.004)	0.130 (0.003)
	c	3.937 (0.892)	2.358 (0.427)	2.908 (0.470)	3.037 (0.326)
R^2 c/		0.79	0.87	0.94	0.94

*Significant ($p = 0.05$) difference in hybrid response to O_3 (sigma and c parameter).

**Significant ($p = 0.01$) difference in hybrid response to O_3 (sigma and c parameter).

a/ R^2 (Weibull model SS/O_3 SS + Hyb SS + O_3 x Hyb SS from ANOVA) for full Weibull model which allows each hybrid to have its own alpha, sigma, and c parameters.

b/ Results of common Weibull model which allows a separate alpha for each hybrid but forces a common sigma and c for all hybrids.

c/ R^2 (Common Weibull model SS/O_3 SS + Hyb SS + O_3 x Hyb SS from ANOVA) for common Weibull model.

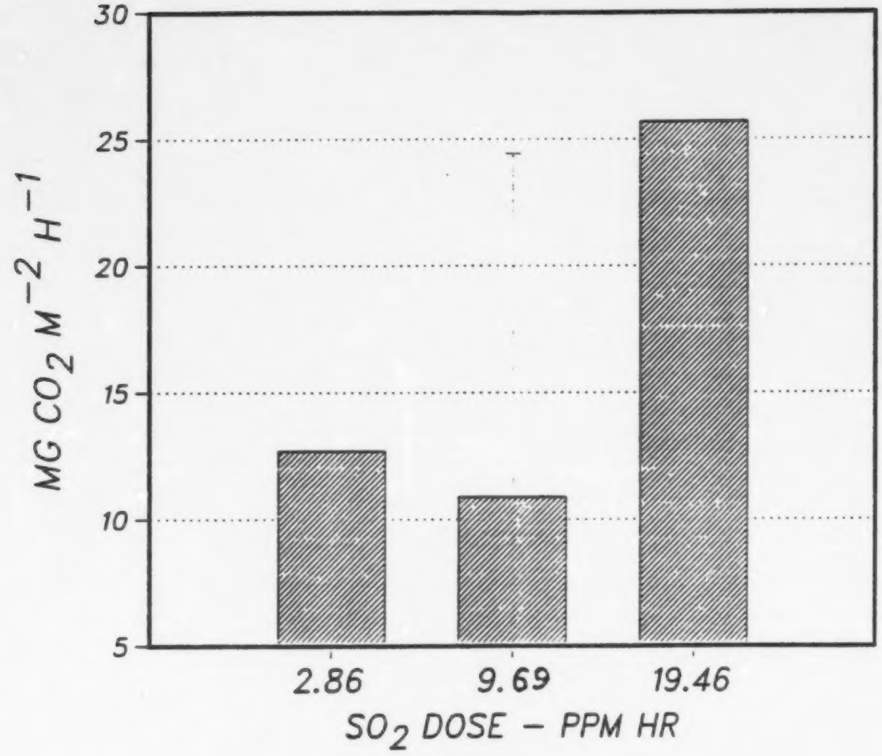

Figure 4.2.2.7. Soil respiration measured in early September in corn plots as a function of SO_2 dose across all O_3 treatments.

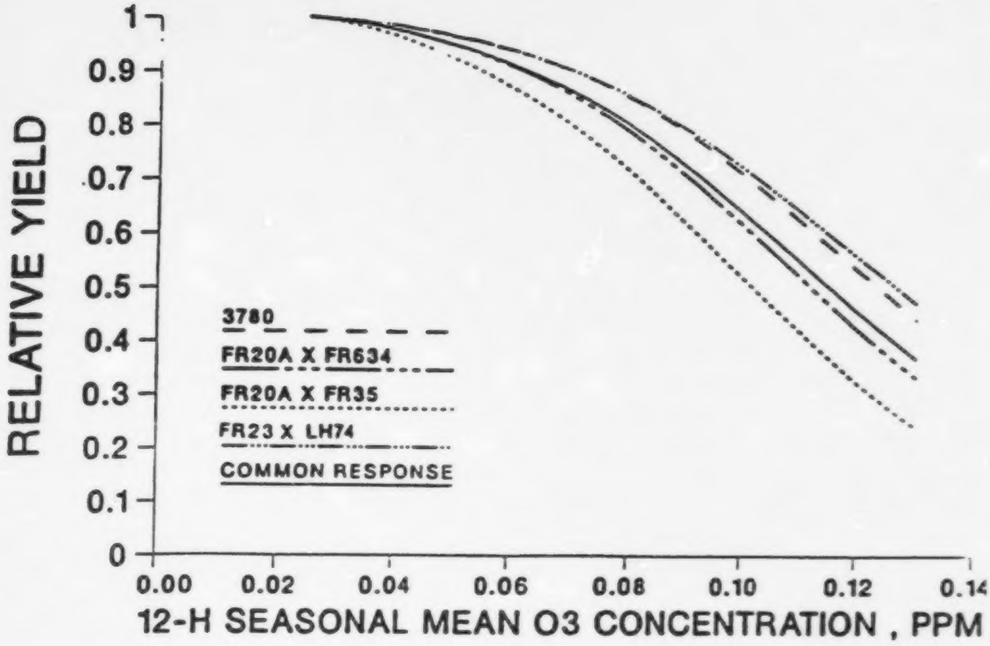

Figure 4.2.2.8. Relative yield response for four field corn hybrids exposed to O_3 in open-top chambers for 12-hr/day for 82 days. Yield was calculated at 100% for 0.025 ppm as an assumed natural background concentration, and averaged across all SO_2 treatments.

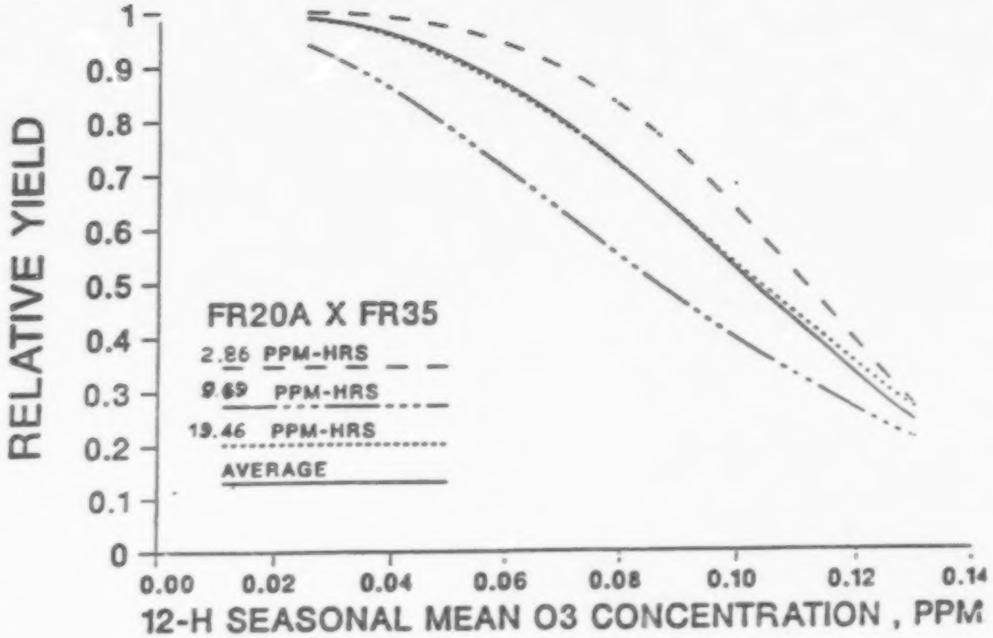

Figure 4.2.2.9. Relative yield response to O_3 of one field corn hybrid at three SO_2 dosages. Plants were exposed to daily and intermittent SO_2 treatments for 82 days.

The models for O_3 response were also run using the mean from the 7-hr window (0900-1600 CST) previously used by NCLAN and the statistical measures (R^2, F values, and Lof) were nearly identical. In fact, the 7-hr mean provided a slightly better fit (by 0.1%) to the yield data. A comparison was also made with the response curve generated for Pioneer 3780 in 1981 at CSRCLAP, and the responses to O_3 in 1981 and 1985 were not different.

4.2.2.4. Discussion

The responses to O_3 observed in this study were similar to those observed previously at Argonne (9). Without the influence of SO_2, the four hybrids were not different in their responses to O_3. The O_3 responses of the four hybrids were also not different from the responses of the two hybrids used in the earlier study, further indicating hybrid similarity and no year effects. However, when the influence of SO_2 was included (SO_2 alone had no effect on yield) significant ($p = 0.05$) hybrid variability was noted at the intermediate SO_2 level and when the O_3 effect was averaged across all SO_2 treatments. There also was an $O_3 \times SO_2$ interaction such that SO_2 caused increases in grain yield in low O_3 environments and decreases in yield in elevated (> 0.07 ppm) O_3 environments. Sulfur dioxide tended to reduce the apparent "plateau" effect in O_3 response (lowered the O_3 threshold) that had been seen in other studies (9,26).

The results of this study indicate greater sensitivity of field corn to O_3 than previously reported, most likely due to hybrids of greater sensitivity being tested. Significant hybrid differences were noted in O_3 sensitivity, and those differences were exacerbated by the presence of SO_2. The O_3-induced yield losses in field corn were also enhanced by exposure to SO_2 at all O_3 exposure concentrations. These results are pertinent, especially in areas where point source SO_2 exposure may be superimposed on a regional O_3 exposure.

4.3. The Adequacy of Shared-Time Monitoring Data in the Development of Different Mean O_3 Values

4.3.1. Evaluation of the Effects of Time-Share Monitoring on Determining the Hourly and Exposure Period Concentrations of O_3(NERCLAP)--

Robert Kohut and John Laurence

4.3.1.1. Introduction

Open-top chambers are used to expose plants to controlled levels of O_3 in field studies conducted by the National Crop Loss Assessment Network (NCLAN). Since each experiment may use as many as 40 chambers, expense and logistics make it infeasible to use separate O_3 monitors for each chamber. As a result, the monitors are used in time-share systems where a single monitor will sequence through a number of chambers and provide one to three short-term observations of pollutant concentrations in a chamber each hour. The concentrations of O_3 in a chamber are dependent upon interactions among the ambient concentration of O_3, the amount of O_3 added, and the ambient wind velocity which affects the rate of ingress of air into the chamber.

The accuracy with which time-share monitoring characterizes the concentrations of O_3 in the chambers was initially evaluated in the 1983 NCLAN Annual Report (27). This report presents the results of additional assessments that were conducted in 1985 at the Boyce Thompson Institute for Plant Research.

4.3.1.2. Methods and Materials

Two open-top chambers containing a mixed forage stand of timothy (*Phleum pratense*) and red clover (*Trifolium pratense*) were monitored for O_3 from 14 September to 3 October. One chamber received nonfiltered air (NF) and the other received additions of O_3 for 12 hr each day (0800 to 2000 hr EDT) to maintain a concentration of O_3 that was twice ambient (NF x 2.0). The pollutant concentrations in each chamber were monitored with Dasibi Model 1003 O_3 monitors incorporated into a data logging system to provide 35 observations each hour for each chamber. The suite of 35 observations was used to calculate the average hourly concentrations of O_3 that would have been produced at sampling rates of 1, 2, 3, 5, 10, 15, and 35 observations per hour. At each sampling frequency, the selected observations were regularly spaced within the hour to simulate the systematic nature of time-share monitoring. One-hour, 12-hr daily, and 12-hr average concentrations of O_3 were calculated for each observation frequency for the 20-day period of 14 September through 3 October.

Regression analysis was conducted to assess the relationships between the hourly values produced with 1, 2, 3, 5, 10, and 15 observations per hour and those produced with 35 observations. To assess the variability in the concentrations of O_3 that could be produced at each sampling frequency, all possible combinations of observations that could have been obtained out of the suite of 35 that were available for each hour were evaluated. This procedure produced 35, 17, 12, 7, 4 and 2 subsets of observations for each hour for the sampling frequencies of 1, 2, 3, 5, 10 and 15 observations per hour, respectively. Each subset was used to produce an average hourly concentration of O_3 that was compared with the average produced from the 35 observations per hour using regression analysis and correlation.

4.3.1.3. Results

The 1-hr and 12-hr average concentrations of O_3 as determined by the various frequencies of observation for several of the 20 monitoring days are presented in Tables 4.3.1.1. and 4.3.1.2. The hourly concentrations of O_3 obtained in the NF chamber with one observation per hour are generally within 4 ppb of concentrations obtained with 35 observations per hour. In the NF x 2.0 chamber, the estimates obtained with one observation per hour often show deviations greater than 30 ppb from those obtained with 35 observations. The deviations are the largest when the concentration of O_3 is greater than 100 ppb and when there is a rapid rate of change in concentration from one hour to the next. The accuracy of the estimate in the O_3-addition chamber is improved considerably when the frequency of observation is increased to two or three per hour. The daily exposure-period average concentrations of O_3 for the days presented in Tables 4.3.1.1. and 4.3.1.2. are similar at all frequencies of observation in the NF chamber and show the best correspondence at frequencies of 2 or greater in the NF x 2.0 chamber. The average concentrations of O_3 determined with each sample frequency over the 20 days of monitoring are presented in Table 4.3.1.3. When averaged over this period, there are essentially no differences in the concentrations of exposure as determined with any of the frequencies of observation.

Regression analysis indicated that in all instances there were significant regressions between the hourly average concentrations of O_3 determined by the rates of 1, 2, 3, 5, 10, and 15 observations per hour and those determined by 35 observations. The correlation coefficients for the analyses are presented in Table 4.3.1.4. All correlations were above .93 and observation frequencies of 2 or more per hour produced correlations greater than .99.

4.3.1.4. Discussion

The results of this study are in agreement with those obtained in the previous evaluation of the time-share process. The daily and monitoring period 12-hr average concentrations of O_3 were nearly identical for all observation frequencies. The degree of similarity in the concentrations obtained with the various observation frequencies can be considered to be directly proportional to the duration of the monitoring period in hours or days and inversely proportional to the dynamics of the exposure concentrations during that period. Since the index of exposure that has been used in the NCLAN program is the seasonal 12-hr average concentration of O_3, the time-share approach to monitoring appears to be satisfactory since it accurately assesses this parameter.

Characterization of the O_3 exposure regimes in NCLAN includes determining the maximum 12-hr exposure, the maximum 1-hr concentration, the seasonal average of the daily 1-hr maxima, and the number of hours of

Table 4.3.1.1. Hourly and daily exposure period concentrations of O_3 in the nonfiltered chamber (NF) determined with various frequencies of observations per hour. All concentrations in parts per billion (ppb).

		Observations per Hour						
Date	Hour	1	2	3	5	10	15	35
September 16	9	3	5	4	4	5	4	4
	10	7	7	7	7	7	7	7
	11	25	26	29	26	27	26	27
	12	32	36	35	36	36	35	36
	13	42	39	41	39	40	39	39
	14	44	42	42	42	42	42	42
	15	44	44	43	43	43	43	43
	16	44	45	43	45	44	45	45
	17	44	44	44	45	44	43	44
	18	40	40	40	42	41	41	41
	19	41	39	37	37	39	39	38
	20	27	30	29	29	29	29	29
	x	33	33	33	33	33	33	33
September 17	9	29	29	28	27	28	27	27
	10	37	33	36	34	33	33	34
	11	43	40	44	43	41	42	42
	12	56	54	55	55	56	54	55
	13	68	66	67	67	66	66	66
	14	74	72	74	74	73	73	73
	15	80	82	79	81	79	80	80
	16	79	79	79	77	78	78	78
	17	77	74	76	77	76	77	77
	18	72	77	74	72	75	73	74
	19	76	71	76	75	74	74	74
	20	69	72	72	72	73	72	72
	x	63	63	63	63	63	63	63
September 18	10	56	59	61	61	60	61	61
	11	65	65	67	66	64	61	63
	12	67	63	67	67	67	66	67
	13	80	78	74	74	75	76	75
	14	82	80	81	79	79	79	79
	15	80	77	78	78	77	79	78
	16	83	82	81	80	79	79	79
	17	78	69	76	72	76	74	75

Table 4.3.1.1. Continued

		Observations per Hour						
Date	Hour	1	2	3	5	10	15	35
September 18	18	68	76	69	67	73	70	70
	19	50	43	53	53	49	51	51
	20	46	45	48	47	48	47	47
	x	69	67	69	68	68	68	68
September 19	9	9	11	12	11	11	10	11
	10	22	23	16	17	21	16	18
	11	57	59	56	56	58	57	58
	12	74	79	74	74	76	74	74
	13	79	79	81	82	79	80	80
	14	90	92	86	87	88	87	87
	15	81	81	85	87	85	87	86
	16	76	79	77	77	77	77	77
	17	72	73	72	72	72	72	72
	18	66	64	66	65	64	65	65
	19	72	76	70	71	70	70	70
	20	50	38	44	39	44	43	43
	x	62	63	62	62	63	62	62
September 20	9	9	9	9	9	9	11	10
	10	19	27	22	20	25	22	24
	13	65	68	66	66	65	66	66
	14	65	60	65	66	64	65	65
	16	69	64	68	66	65	66	66
	17	78	79	77	78	77	77	77
	18	76	75	77	74	75	75	74
	19	66	66	61	67	65	66	66
	20	43	53	48	49	50	49	49
	x	54	56	55	55	55	56	56
September 21	9	43	44	44	39	38	40	39
	10	39	44	46	44	43	42	43
	11	63	59	59	60	58	59	59
	12	57	55	60	57	56	55	56
	13	57	56	59	58	57	58	57
	14	61	59	59	60	60	58	59
	15	63	60	59	61	61	61	61
	16	63	60	61	61	61	61	61
	17	51	52	51	51	52	52	52

Table 4.3.1.1. Continued

		Observations per Hour						
Date	Hour	1	2	3	5	10	15	35
September 21	18	44	42	42	43	42	42	42
	19	34	35	34	34	36	36	35
	20	24	20	23	22	21	22	22
	x	50	49	50	49	49	49	49

Table 4.3.1.2. Hourly and daily exposure period concentrations of O_3 in the O_3-added chamber (NF x 2.0) determined with various frequencies of observations per hour. All concentrations in parts per billion (ppb).

		Observations per Hour						
Date	Hour	1	2	3	5	10	15	35
September 16	9	4	4	5	4	4	4	4
	10	6	7	7	7	8	6	7
	11	20	26	27	27	27	26	27
	12	56	66	66	62	64	63	64
	13	77	75	71	74	72	74	73
	14	69	71	74	74	71	72	73
	15	78	77	78	76	78	77	77
	16	76	81	81	80	79	83	81
	17	82	78	83	85	81	82	82
	18	85	76	80	81	79	80	80
	19	80	80	79	77	79	78	78
	20	29	30	30	30	32	33	32
	x	55	56	57	57	57	57	57
September 17	9	27	28	27	26	27	26	26
	10	34	34	35	37	36	34	36
	11	42	41	41	47	42	44	43
	12	54	53	53	53	55	52	54
	13	141	129	99	106	106	99	102
	14	153	130	120	122	121	125	124
	15	140	146	127	135	138	147	140
	16	113	151	134	136	145	134	137
	17	182	151	151	145	146	145	144
	18	141	134	152	151	142	145	143
	19	150	149	150	151	140	137	142
	20	69	71	70	71	72	74	72
	x	104	102	97	99	98	97	98
September 10	10	98	95	90	90	96	92	93
	11	108	106	99	113	104	106	107
	12	132	134	125	127	123	121	124
	13	165	1[illegible]4	136	141	136	140	138
	14	171	138	149	152	144	151	148
	15	166	147	155	161	148	154	154
	16	149	159	160	157	157	161	160
	17	173	156	159	151	157	151	154

Table 4.3.1.2. Continued

		Observations per Hour						
Date	Hour	1	2	3	5	10	15	35
September 10	18	139	142	139	143	142	143	142
	19	108	102	104	110	103	109	105
	20	47	46	47	46	47	46	46
	x	132	125	124	127	124	125	125
September 19	9	8	9	11	10	10	10	10
	10	21	16	15	16	17	15	16
	11	127	136	120	119	120	111	118
	12	123	162	135	154	147	137	143
	13	147	146	165	159	159	153	157
	14	159	160	169	166	163	162	163
	15	159	163	156	164	161	162	162
	16	151	132	143	140	143	145	142
	17	127	138	141	139	136	136	137
	18	134	133	137	136	132	134	134
	19	148	141	134	134	137	134	136
	20	46	36	44	38	43	46	43
	x	113	115	115	115	115	113	114
September 20	9	8	8	8	7	8	8	8
	10	24	25	20	20	23	22	22
	13	110	123	124	122	118	120	119
	14	145	132	133	120	131	131	130
	16	120	132	120	119	131	126	128
	17	108	120	107	122	122	122	122
	18	135	129	128	138	135	136	136
	19	146	128	132	136	131	132	131
	20	41	46	44	44	44	43	43
	x	93	94	91	92	94	94	94
September 21	9	41	43	40	38	36	38	37
	10	50	75	64	67	73	66	71
	11	106	117	99	110	112	108	109
	12	106	114	104	109	107	108	107
	13	112	109	113	109	109	113	111
	14	106	107	107	107	110	108	109
	15	108	114	110	116	118	119	119

Table 4.3.1.2. Continued

		Observations per Hour						
Date	Hour	1	2	3	5	10	15	35
	16	122	123	121	120	122	121	121
	17	116	107	108	108	112	106	108
	18	104	97	95	95	97	95	96
	19	94	86	79	83	83	88	84
	20	23	19	21	19	19	20	19
	x	91	93	89	91	92	91	91

Table 4.3.1.3. The 20-day average exposure period concentrations of O_3 calculated at various rates of observations per hour. All concentrations in parts per billion (ppb).

Observations per Hour	Nonfiltered Chamber	Ozone-added Chamber
1	42	70
2	42	68
3	42	68
5	42	68
10	42	68
15	42	68
35	42	68

Table 4.3.1.4. Summary of the correlation coefficients in an evaluation of relationships between the average hourly concentrations of O_3 as determined by 1, 2, 3, 5, 10, and 15 observations per hour and those determined by 35 observations per hour in both nonfiltered and O_3-added chambers.

Nonfiltered Chamber			Ozone-added Chamber		
Observations per Hour	Subset[a]	Correlation Coefficient	Observations per Hour	Subset	Correlation Coefficient
1	1	.971	1	1	.930
	8	.987		8	.974
	15	.993		15	.985
	22	.988		22	.974
	29	.982		29	.974
2	1	.992	2	1	.981
	5	.996		5	.991
	9	.996		9	.990
	13	.996		13	.992
	17	.992		17	.998
3	1	.996	3	1	.991
	3	.998		3	.994
	5	.998		5	.995
	7	.998		7	.995
	9	.996		9	.993
5	1	.998	5	1	.996
	2	.999		2	.997
	3	.999		3	.997
	4	.999		4	.998
	5	.999		5	.997
	6	.999		6	.997
	7	.998		7	.995
10	1	.999	10	1	.999
	2	.999		2	.999
	3	.999		3	.999
	4	.999		4	.998
15	1	.999	15	1	.999
	2	.999		2	.999

[a] Subsets presented are 5 out of 35, 5 out of 17, and 5 out of 12 for 1, 2, and 3 observations per hour, respectively, and all 7, 4, and 2 subsets for 5, 10, and 15 observations per hour, respectively.

exposure above 0.08 and 0.12 ppm. Since both the maximum 12-hr exposure and the seasonal average of the daily 1-hr maxima involve determining an average over an extended period of time, observation frequency is not a significant factor affecting the accuracy of these measurements. Exposure regime parameters that involve only individual hourly observations may be somewhat affected by the frequency of the observations. The results of this assessment indicate, however, that frequencies of three or more observations per hour should provide accurate assessments of individual hourly average concentrations of O_3.

4.3.2. Adequacy of Time-Shared Monitoring Data for Estimating Hourly, Daily, and Seasonal Concentrations of O_3 (CSRCLAP)--L.W. Kress

4.3.2.1. Introduction

Due to constraints in funding and limitations in available equipment, time-sharing of pollutant monitoring equipment is a necessity of any large multi-plot field experiment. Monitoring systems sequence through a number of sample points (e.g., open-top chambers) to provide one to a few short-term (2-3 minute) observations per hour for each point.

To assess the adequacy of O_3 concentration estimates collected by time-share systems, we sampled a single chamber continuously and evaluated the data as 30 individual 2-min readings per hour.

4.3.2.2. Methods and Materials

One open-top chamber containing a stand of field corn exposed to O_3 at 2.5 times ambient was monitored continuously from 1 July to 31 August. Ozone was added whenever the ambient O_3 was above 0.03 ppm between 0800-2000 CDT. The O_3 monitor was a Bendix 8002 chemiluminescent analyzer. All standard NCLAN QA procedures were followed. Data were collected on a strip chart which was read on an X-Y digitizer as individual 2-min readings to simulate the data collected on the time-share system used at Argonne.

Once entered into the computer, each 2-min reading was used to generate hourly and daily 12-hr concentration estimates. To simulate the time-share system, observation frequencies of 1, 2, 3, 4, 5, 6, 7, 8, 15, and 30 per hour were selected (Table 4.3.2.1.). The sampling frequencies of 1, 2, and 3 were each replicated three times using different sets of values out of the 30 available for each hour. The 1-hr, 12-hr daily, and 12-hr seasonal mean concentrations of O_3 were calculated for each sampling frequency.

4.3.2.3. Results

The 1-hr and 12-hr mean concentrations of O_3 as estimated using the various sampling frequencies are presented for one week in July and one week in August in Tables 4.3.2.2.-4.3.2.15. On some days there is little difference (< 5%) between the concentration estimates from any of the sampling frequencies (Tables 4.3.2.2., 4.3.2.5., 4.3.2.6., 4.3.2.9., 4.3.2.11.). Rarely is the difference among sampling rates of two or more greater than 5 percent (Tables 4.3.2.4., 4.2.3.15.). The differences occur on days with gusty winds and when the O_3 addition begins or terminates in mid-hour.

The 2-month seasonal means show little difference in the 12-hr values at all sample frequencies (Table 4.3.2.16.). The seasonal means for each hour show considerable variation at sample frequencies of one or two observations per hour at the beginning and end of the day when O_3 additions often started late or ended early. The mid-day hours (1200-1900) show good agreement at all sampling frequencies.

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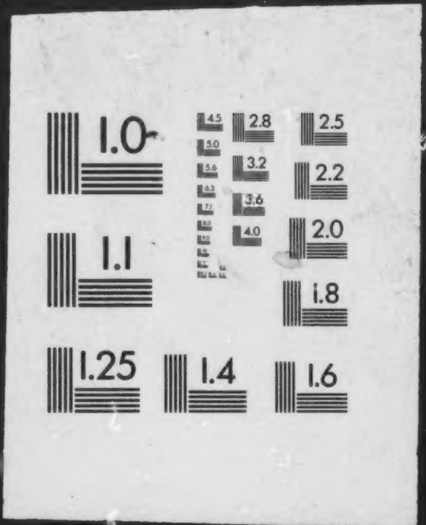
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4.5
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1.1
1.8
1.25
1.4
1.6

Table 4.3.2.1. Observations chosen to simulate a time-shared monitoring system used to estimate O_3 concentrations over a range of sampling frequencies.

Sampling Frequency No. of 2-min Samples/hr	Observation Number[a]
1	15
1-1	7
1-2	23
2	8, 23
2-1	7, 22
2-2	1, 16
3	6, 16, 26
3-1	1, 11, 21
3-2	3, 13, 23
4	4, 11, 19, 27
5	6, 12, 18, 24, 30
6	1, 6, 11, 16, 21, 26
7	2, 6, 11, 15, 19, 23, 28
8	1, 5, 8, 12, 16, 20, 24, 28
15	All odd numbers
30	All

[a] For sampling frequency = 2, a number between 1 and 15 was selected at random and the second number was equally spaced between 16 and 30. For sampling frequency = 3, a number between 1 and 10 was randomly selected. For sampling frequencies of 4 and above, a random number between 1 and 30 was selected and the other numbers were equally spaced.

Table 4.3.2.2. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 6 July 1985.

Hour[a]	No. of Samples per Hour											Ambient[c]	Wind Speed[d] m/s
	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]		
8-9	23	24	30	27	24	27	25	26	25	27	27 (5)	30	3.1
9-10	83	83	98	92	60	80	52	76	70	74	74 (14)	35	2.9
10-11	72	75	67	76	73	76	79	77	78	75	76 (8)	37	3.4
11-12	79	70	66	71	73	78	75	74	76	75	75 (8)	40	3.1
12-13	109	83	76	82	94	98	89	81	91	86	87 (13)	44	3.1
13-14	87	89	84	87	92	85	84	87	93	94	94 (16)	46	2.7
14-15	89	92	111	102	113	101	102	101	106	101	103 (15)	47	2.1
15-16	114	106	94	92	112	124	99	117	110	109	111 (16)	46	1.9
16-17	101	102	112	121	97	98	112	112	104	107	106 (13)	45	2.4
17-18	102	106	104	105	106	107	108	107	108	106	107 (3)	48	1.7
18-19	121	101	112	103	114	108	114	111	110	110	110 (9)	44	1.5
19-20	105	104	87	95	99	99	100	98	100	101	100 (7)	40	0.5
Avg.	90	86	87	88	88	90	87	89	89	89	89 (3)	42	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.3. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 7 July 1985.

Hour[a]	No. of Samples per Hour											Ambient[c]	Wind Speed[d] m/s
	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]		
9	20	19	23	21	18	20	19	21	20	20	20 (3)	23	2.2
10	23	18	95	56	31	51	47	54	49	49	50 (37)	33	2.3
11	100	70	101	86	83	96	81	98	89	90	92 (23)	50	2.8
12	107	124	103	104	125	111	126	110	113	112	113 (12)	61	3.8
13	99	107	120	116	100	112	95	98	100	100	101 (10)	65	4.3
14	101	95	96	93	103	107	100	97	100	98	100 (6)	61	4.2
15	100	96	101	98	105	99	101	97	100	100	99 (4)	59	4.5
16	99	101	98	100	97	98	100	99	98	99	99 (4)	62	4.7
17	107	109	103	106	106	106	103	106	105	106	106 (4)	63	4.7
18	109	107	108	112	103	105	106	108	108	107	108 (3)	67	4.2
19	105	111	104	106	106	105	104	106	106	106	105 (3)	65	4.3
20	113	110	106	107	111	110	108	108	109	110	110 (5)	67	3.0
Avg.	90	89	97	92	90	93	91	92	91	91	92 (5)	57	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.4. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 8 July 1985.

Hour[a]	No. of Samples per Hour											Ambient[c]	Wind Speed[d] m/s
	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]		
9	99	74	96	100	67	94	73	90	83	85	87 (13)	39	2.5
10	106	94	73	87	96	94	96	97	96	95	96 (14)	46	3.0
11	98	85	89	86	96	93	90	102	95	92	93 (10)	56	2.3
12	135	124	132	117	106	128	105	127	111	120	120 (15)	68	2.7
13	120	110	117	110	119	106	115	107	111	113	112 (13)	72	2.8
14	143	114	119	122	128	117	123	118	118	122	121 (10)	75	3.5
15	129	128	131	137	122	129	122	131	129	130	129 (8)	89	4.0
16	172	117	121	119	151	143	123	132	135	124	128 (18)	82	3.8
17	128	139	117	126	121	130	126	136	122	126	126 (12)	78	3.5
18	152	112	163	146	114	120	125	135	121	139	135 (21)	73	2.9
19	135	127	74	102	114	147	111	104	114	112	116 (32)	75	2.1
20	63	70	58	62	67	61	65	61	63	63	63 (5)	70	1.9
Avg.	123	108	108	109	108	114	106	111	108	110	110 (6)	69	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.5. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 9 July 1985.

Hour[a]	No. of Samples per Hour											Ambient[c]	Wind Speed[d] m/s
	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]		
9	23	17	24	20	20	21	21	23	21	21	21 (3)	26	0.9
10	88	34	93	69	63	75	57	71	71	79	79 (25)	45	1.2
11	91	99	102	104	92	101	103	104	103	103	103 (6)	58	1.4
12	118	102	136	118	112	122	114	123	117	118	118 (14)	64	1.6
13	136	141	155	146	130	135	137	144	139	138	140 (11)	74	1.7
14	170	137	163	156	139	140	145	162	149	147	150 (14)	77	2.1
15	129	130	142	152	160	132	145	131	152	142	141 (15)	75	2.4
16	128	147	110	123	137	136	135	123	128	131	129 (13)	75	1.6
17	192	173	166	170	165	168	175	170	168	177	175 (14)	80	1.8
18	142	178	181	168	171	157	168	163	165	171	168 (18)	79	0.9
19	196	192	190	190	190	192	185	190	191	188	189 (6)	84	0.2
20	151	181	51	122	174	128	159	129	145	138	136 (61)	77	1.4
Avg.	130	128	126	128	129	126	129	128	129	129	129 (3)	68	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.6. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 10 July 1985.

	No. of Samples per Hour												
Hour[a]	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]	Ambient[c]	Wind Speed[d] m/s
9	29	24	28	27	25	27	25	27	26	27	27 (2)	28	2.4
10	37	30	61	46	33	46	42	51	42	45	46 (16)	32	2.5
11	70	66	68	65	62	71	65	80	70	70	72 (11)	39	2.9
12	85	67	88	81	73	80	77	84	81	80	80 (7)	47	2.9
13	85	99	99	94	91	96	83	97	97	91	91 (10)	50	2.8
14	95	98	82	83	101	85	95	95	95	94	93 (12)	52	2.5
15	119	117	119	127	115	104	112	102	109	109	108 (12)	56	2.0
16	90	134	91	97	117	121	117	118	109	115	114 (13)	60	2.0
17	136	116	136	131	127	124	120	118	119	127	126 (11)	61	1.9
18	105	129	120	131	114	122	117	121	118	118	119 (10)	62	1.3
19	117	113	126	118	122	117	121	120	120	120	120 (6)	67	0.6
20	126	120	128	125	125	124	125	125	125	124	125 (4)	64	0.4
Avg.	91	93	96	93	92	93	92	95	93	93	93 (3)	52	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.7. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 11 July 1985.

Hour[a]	No. of Samples per Hour											Ambient[c]	Wind Speed[d] m/s
	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]		
9	22	59	15	37	22	36	32	38	36	35	35 (22)	24	1.6
10	100	34	79	89	62	70	68	82	73	73	75 (27)	42	2.4
11	104	74	86	85	104	82	93	83	92	89	89 (13)	58	2.3
12	128	79	102	94	108	89	96	93	102	93	95 (15)	47	1.9
13	89	112	83	94	103	103	99	105	105	103	103 (13)	55	2.2
14	129	83	129	112	88	100	99	112	111	113	112 (15)	53	1.7
15	125	104	135	128	112	124	110	131	121	121	123 (14)	69	1.3
16	142	143	144	145	142	140	138	135	140	143	142 (9)	72	1.2
17	153	144	141	143	151	142	144	145	143	142	143 (8)	72	1.4
18	143	137	134	133	140	139	135	134	137	137	137 (5)	69	1.3
19	137	138	143	142	139	136	138	139	138	137	138 (5)	65	1.1
20	131	139	127	131	131	130	135	126	132	131	130 (10)	57	1.2
Avg.	117	104	110	111	108	108	107	110	111	110	100 (4)	58	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.8. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 12 July 1985.

Hour[a]	No. of Samples per Hour											Ambient[c]	Wind Speed[d] m/s
	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]		
9	38	32	90	64	27	54	44	62	51	54	54 (28)	41	0.6
10	84	76	84	80	83	85	82	83	82	82	82 (5)	41	0.7
11	84	88	87	85	85	86	85	86	85	85	85 (2)	46	1.0
12	107	87	108	98	98	101	98	99	97	98	99 (10)	57	1.6
13	87	85	94	88	86	91	88	94	89	90	90 (10)	59	1.8
14	128	121	116	113	120	122	112	116	116	118	117 (8)	75	1.8
15	132	120	129	127	134	136	132	131	130	133	133 (11)	74	1.9
16	117	136	146	141	136	120	140	136	134	134	133 (13)	69	1.8
17	148	138	137	139	136	131	135	131	135	138	136 (7)	66	1.6
18	122	137	139	137	140	137	143	127	136	139	136 (9)	62	1.5
19	132	127	112	122	116	122	117	115	119	122	122 (9)	55	1.6
20	114	99	86	93	112	99	101	99	99	99	99 (13)	43	0.5
Avg.	107	104	111	107	106	107	106	107	106	108	107 (3)	58	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.9. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 6 August 1985.

	No. of Samples per Hour												
Hour[a]	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]	Ambient[c]	Wind Speed[d] m/s
9	10	6	13	10	6	7	6	10	8	7	8 (4)	14	1.9
10	18	18	22	21	16	18	18	18	17	18	18 (5)	28	2.0
11	86	74	93	86	55	87	69	91	80	83	84 (20)	40	2.2
12	96	98	106	103	99	103	98	102	101	101	102 (5)	27	2.1
13	117	114	110	114	112	117	111	117	116	113	115 (6)	52	2.0
14	135	123	121	120	129	128	125	125	125	125	124 (6)	54	2.1
15	119	111	127	123	117	119	121	121	122	121	122 (10)	53	2.7
16	127	131	141	139	132	131	135	136	136	133	134 (8)	52	2.4
17	118	135	108	121	127	118	123	116	121	120	120 (13)	44	1.3
18	114	109	109	110	109	110	109	110	110	110	110 (3)	45	1.3
19	101	106	98	102	104	97	100	94	100	100	99 (8)	41	2.4
20	93	87	87	93	87	94	91	90	92	89	90 (9)	35	2.9
Avg.	95	93	95	95	91	94	92	94	94	93	94 (2)	40	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.10. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 7 August 1985.

Hour[a]	No. of Samples per Hour											Ambient[c]	Wind Speed[d] m/s
	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]		
9	5	6	12	10	7	8	8	9	9	8	8 (3)	13	1.9
10	15	8	14	12	11	12	11	13	12	12	12 (3)	20	1.6
11	28	19	109	64	21	51	22	56	51	44	46 (39)	35	1.9
12	113	101	131	116	99	107	107	118	109	113	113 (13)	49	1.9
13	132	118	116	119	130	136	126	134	126	130	130 (7)	57	2.1
14	129	117	135	138	124	126	130	130	130	130	130 (7)	58	2.1
15	143	129	138	136	133	138	136	143	137	138	139 (6)	57	2.1
16	132	125	139	137	133	134	131	136	135	134	133 (5)	59	2.0
17	138	130	128	133	132	130	136	127	133	131	130 (9)	55	2.1
18	128	129	119	122	128	130	124	130	126	127	127 (5)	54	2.0
19	129	122	131	128	125	128	126	128	128	129	129 (5)	50	0.6
20	123	135	122	127	125	124	129	115	127	126	124 (14)	41	0.4
Avg.	101	95	108	103	97	102	99	103	101	103	102 (4)	45	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.11. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 8 August 1985.

	No. of Samples per Hour												
Hour[a]	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]	Ambient[c]	Wind Speed[d] m/s
9	13	6	18	13	9	13	11	14	12	13	13 (6)	25	0.7
10	25	26	83	55	21	22	42	32	31	36	35 (24)	32	0.9
11	26	30	33	31	26	58	27	45	40	44	45 (33)	39	1.4
12	116	112	123	120	116	120	109	117	117	116	116 (6)	52	1.8
13	138	128	149	137	130	128	135	134	135	134	134 (9)	63	2.0
14	132	126	132	127	131	130	123	128	128	127	127 (9)	58	1.9
15	142	152	154	137	140	152	137	145	141	142	142 (13)	66	1.6
16	156	153	143	145	161	158	161	160	158	158	159 (9)	77	1.8
17	183	191	188	195	157	164	182	175	179	183	181 (15)	81	1.7
18	195	190	173	181	192	179	186	172	182	179	178 (14)	76	1.3
19	187	180	184	181	166	184	169	182	176	178	178 (10)	71	0.3
20	194	185	159	175	182	183	168	167	172	171	171 (25)	68	0.6
Avg.	126	123	128	124	119	124	121	123	123	123	123 (5)	59	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.12. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 9 August 1985.

	No. of Samples per Hour												
Hour[a]	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]	Ambient[c]	Wind Speed[d] m/s
9	20	18	26	22	19	47	21	35	31	36	36 (32)	30	1.8
10	129	113	132	123	106	116	115	122	119	120	120 (15)	53	2.0
11	145	124	158	153	141	146	146	148	146	142	145 (13)	63	2.5
12	169	158	157	161	153	157	153	168	166	162	164 (10)	73	2.2
13	158	178	184	178	173	169	181	183	177	179	179 (8)	77	2.3
14	180	170	152	166	186	189	183	177	179	175	176 (11)	76	2.3
15	166	145	164	161	170	149	176	167	166	170	169 (14)	75	2.2
16	174	179	177	178	186	172	176	161	171	168	167 (15)	73	2.4
17	172	179	138	158	161	163	177	167	167	170	168 (15)	72	2.2
18	173	152	188	163	171	173	173	176	175	173	172 (17)	70	2.2
19	189	183	201	192	173	173	185	183	184	189	186 (9)	68	1.7
20	184	178	164	181	181	170	192	155	180	178	176 (27)	67	1.3
Avg.	155	148	153	153	151	152	157	153	155	155	155 (4)	67	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.13. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 10 August 1985.

	No. of Samples per Hour												Wind
Hour[a]	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]	Ambient[c]	Speed[d] m/s
9	39	30	61	46	35	46	39	50	44	45	46 (17)	35	2.1
10	79	87	72	79	74	77	76	78	77	77	77 (6)	30	1.7
11	34	34	34	35	55	29	48	33	37	36	35 (12)	29	1.5
12	30	32	23	27	31	27	29	28	28	28	28 (4)	34	2.5
13	68	72	79	77	51	76	61	78	73	70	72 (16)	34	2.6
14	83	84	83	75	81	81	85	83	79	83	82 (5)	37	2.1
15	82	82	129	107	94	96	98	104	103	99	101 (17)	46	1.5
16	124	117	131	125	124	129	126	126	126	128	128 (8)	55	1.0
17	159	152	178	165	145	158	148	161	156	157	158 (12)	69	0.5
18	177	163	171	168	171	169	169	164	170	172	171 (8)	68	1.4
19	137	169	145	150	149	150	150	146	150	149	148 (13)	58	0.5
20	93	119	94	106	112	99	111	87	100	97	96 (23)	41	0.1
Avg.	92	95	100	96	93	95	95	95	95	95	95 (3)	44	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.14. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 11 August 1985.

	No. of Samples per Hour												
Hour[a]	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]	Ambient[c]	Wind Speed[d] m/s
9	17	12	20	17	13	16	14	17	16	16	16 (4)	22	1.8
10	81	26	91	60	49	64	62	75	62	65	66 (30)	36	2.1
11	110	91	94	94	96	99	94	100	97	97	98 (7)	43	2.0
12	112	94	108	102	109	108	104	108	107	107	107 (6)	49	2.1
13	113	107	109	109	111	107	110	108	109	110	109 (4)	53	2.5
14	98	109	102	108	104	108	109	113	109	109	109 (7)	55	2.5
15	116	113	103	109	110	109	117	112	112	115	114 (8)	54	2.3
16	136	129	137	138	125	123	124	130	131	128	129 (6)	57	2.2
17	134	121	142	137	117	128	126	133	129	131	131 (10)	57	2.2
18	141	124	148	140	141	133	139	139	144	139	140 (9)	60	1.7
19	136	130	129	134	130	130	130	128	131	132	131 (7)	49	1.1
20	121	129	112	122	117	124	118	122	121	121	121 (6)	42	1.0
Avg.	110	99	108	106	102	104	104	107	106	106	106 (4)	47	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.15. Hourly and average daily O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient O_3 on 12 August 1985.

Hour[a]	No. of Samples per Hour											Ambient[c]	Wind Speed[d] m/s
	1	1-1	1-2	2	2-1	3	3-1	5	8	15	30[b]		
9	23	22	24	23	22	24	22	24	23	23	24 (2)	27	2.9
10	28	28	28	27	27	42	26	36	33	33	34 (16)	31	2.6
11	79	74	81	78	79	89	76	81	79	78	77 (7)	38	2.6
12	87	103	87	84	89	93	87	97	93	93	93 (1)	47	2.5
13	112	116	125	123	118	118	109	111	115	114	113 (8)	57	2.9
14	140	117	148	133	109	116	111	123	123	123	123 (13)	63	3.1
15	121	139	154	147	131	132	145	140	139	143	143 (25)	68	3.0
16	131	157	165	160	136	144	148	145	140	144	143 (14)	70	3.0
17	160	145	172	162	145	141	158	159	153	154	153 (14)	74	3.0
18	157	189	177	187	154	175	159	177	174	173	174 (15)	71	2.5
19	169	180	174	178	157	175	168	177	175	175	176 (8)	68	2.1
20	177	164	157	161	173	164	174	150	165	166	163 (14)	65	2.3
Avg.	115	120	124	122	111	117	115	119	118	118	118 (5)	57	---

[a] O_3 addition start - 0900, stop - 1955 (CDT).

[b] Number in parenthesis is one standard deviation for the 30 2-min readings for that hour.

[c] Ambient O_3 concentration taken at a 3-m height.

[d] Wind speed at a 1.5-m height. One m/s = 2.237 mph.

Table 4.3.2.16. Hourly and 12-hr seasonal mean O_3 concentration (ppb) estimates generated from various 2-min sampling frequencies in an open-top chamber receiving 2.5 x ambient for the period 1 July - 31 August 1985.

Hour[a]	No. of Samples per Hour															
	1	1a	1b	2	2a	2b	3	3a	3b	4	5	6	7	8	15	30
8-9	25	24	27	25	25	20	26	22	25	26	26	24	25	24	25	25
9-10	39	33	47	41	40	35	40	38	39	41	42	39	40	39	40	40
10-11	64	53	72	64	62	56	64	59	61	64	66	62	63	63	63	64
11-12	88	84	82	87	87	83	88	85	87	88	90	86	87	87	88	88
12-13	101	99	105	102	102	99	101	100	102	101	102	100	102	101	101	101
13-14	112	108	113	111	110	107	110	108	109	111	111	109	111	111	111	111
14-15	118	116	124	121	119	117	119	118	118	119	119	118	119	119	119	119
15-16	130	125	127	126	127	127	127	126	126	127	126	127	127	126	127	126
16-17	123	124	120	124	122	122	121	123	123	122	122	122	122	122	122	122
17-18	119	121	118	119	119	119	119	119	119	120	118	119	119	119	119	119
18-19	112	114	110	112	111	114	112	113	112	110	112	112	112	112	112	112
19-20	99	106	88	97	97	102	95	101	100	96	91	98	97	97	96	96
Mean	94	92	95	94	93	92	94	93	93	94	94	93	94	93	94	94
Std.[b] dev.	35	34	36	35	35	34	34	34	35	35	35	34	35	34	35	35

[a] Ozone additions often began after 0800 and ended prior to 2000.

[b] One standard deviation of the mean O_3 concentration (12-hr seasonal mean) from 1 July - 31 August 1985.

4.3.2.4. Discussion

On most days, sampling frequencies of three or more provide a good estimate of hourly O_3 concentrations. Under calm conditions and stable O_3 concentrations, even one observation per hour may provide accurate hourly estimates. For daily 12-hr means, two observations per hour appear to be adequate and on many days one observation per hour is adequate. For estimates of a seasonal 12-hr mean, sampling frequencies as low as one 2-min sample per hour appear to be perfectly adequate. Since the yield loss estimates generated in the NCLAN program use a seasonal estimate of O_3 exposure, the time-share concept with sampling frequencies as low as one sample per hour appears to be a valid method of providing accurate estimates of O_3 concentrations.

4.4. Quality Assurance for 1985 (NWRCLAP)-- Grady E. Neely and James R. Miller

4.4.1. Air Monitoring

A systems evaluation of uniformity and adherence to quality assurance, (QA) procedures for instrumentation monitoring and dispensing of air pollutants was made between 22 July and 14 August, 1985, at each of the NCLAN sites.[1] The auditor's report [filed with the NCLAN Quality Assurance Officer (QAO)] indicates that in general personnel at all NCLAN locations had a positive attitude toward QA procedures. Active steps were being taken to comply with air monitoring and data acquisition QA components of the studies. To a limited extent, there was some confusion as to the necessity of certain QA procedures.

An annual performance audit of air monitoring analyzers at each NCLAN site was conducted between 13 June and 23 August 1985.[2] The audit results are presented in the "Sixth Performance Audit of the National Crop Loss Assessment Network," by R.W. Murdock, R.C. Shores, and C. Wall, on file with the QAO in Corvallis.

The accuracies of the analyzers at the research locations audited in 1980 through 1985 are shown in Table 4.4.1. A result of excellent, satisfactory, or unsatisfactory indicates the response of the analyzer was within 5, 5-15, or greater than 15 percent, respectively, of the known amount of standard gas presented to the analyzer. A summary of the results for 1985 reveal that for the 22 O_3 analyzers audited, 19 were excellent and 3 were satisfactory. Of the 8 SO_2 instruments audited, 3 were excellent and 5 were satisfactory. The results of the audit for the total oxides of nitrogen monitor revealed that the NO and NO_x channels were excellent and the NO_2 channel was satisfactory (data not shown). No carbon dioxide analyzers were in use this year. Calibration standards in use at all locations were noted to be within their certification date.

Table 4.4.2. gives the results of the zero and span checks conducted at each site. Zero and span checks data give an indication of the precision of the analyzers at the 95% confidence level.

To more nearly determine treatment concentrations in NCLAN studies, a correction factor for each chamber is calculated from the measured line

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[1] Audit conducted by Jeffrey C. Sprenger, QA Coordinator, Northrop Services, Inc., Corvallis, Oregon, under Support Contractor Technical Directive No. AP-12-03-85.

[2] Performance audit conducted by personnel of the Research Triangle Institute (RTI), Research Triangle Park, North Carolina 27711, under EPA Contract No. 68-02-4125.

Table 4.4.1. Summary of NCLAN analyzer audits from 1980 through 1985.

Audit Site and Date	Ozone			Sulfur Dioxide			Nitrogen Oxides			Carbon Dioxide			Total
	E	S	U/I	E	S	U/I	E	S	U/I	E	S	U/I	
Argonne													
July 1981	2	3		2	3			1					11
Sept. 1981	3	1	1	2		3		1	1				12
Sept. 1982	1	2		1	1				1				6
Sept. 1983	2	1	2		3				1				9
July 1984	3	2			4			1					10
July 1985	7	1		3	1			1					13
Boyce Thompson													
Sept. 1980	1	2	1	1	1								6
July 1981	4			2	2					1			9
Sept. 1981	5			1	3							1	10
Sept. 1982	4	1		2	2								9
Sept. 1983		4		2	2			1					9
July 1984	4	1		1	3								9
July 1985	6	1			4								11
Raleigh													
Sept. 1980					1	1							2
July 1981		4		2	2				1				9
Sept. 1981	4			3	1				1				9
Sept. 1982	3	2		2			1						8
Sept. 1983	2	1			1		2						6
Aug. 1984	4	1											5
Aug. 1985	3	1											4
Shafter													
Sept. 1981	3		1										4
Aug. 1982	2	2											4
Sept. 1983	2	2											4
July 1984	3	1		1									5
Aug. 1985	3												3
Totals													
1980	1	2	1	1	2	1							8
1981	21	8	2	12	11	3		2	3	1		1	64
1982	10	7		5	3		1		1				27
1983	6	8	2	2	6		2	1	1				28
1984	14	5		2	7			1					29
1985	19	3		3	5			1					31

E = Excellent; S = Satisfactory; U = Unsatisfactory; I = Inoperative.

Table 4.4.2. Summary of NCLAN analyzer precision in 1985.

							95% Prob	
Site	Analyzer	Serial Number	Dates in Service	Pts.	% Δ Mean	Std. Dev.	Upper Limit	Lower Limit
Argonne	Bendix/O_3	26761-30	6/20-9/14	52	-0.2	2.6	5.0	- 5.3
	Bendix/O_3	37137	6/15-9/26	37	-0.4	3.5	6.4	- 7.2
	Bendix/O_3	32937	6/10-9/30	42	-1.7	2.8	3.8	- 7.3
	Bendix/O_3	32977	4/22-8/26	37	-0.9	14.2	27.0	-28.7
	Bendix/O_3	30045-2	6/17-9/30	35	-1.6	10.3	18.6	-21.9
	Bendix/O_3	26761-11	6/20-9/16	56	-0.7	2.0	3.2	- 4.6
	Bendix/O_3	26761-15	6/22-9/16	41	-1.0	4.0	6.9	- 8.9
	Bendix/O_3	7503	6/15-9/28	56	-0.4	4.3	8.0	8.7
	Bendix/O_3	26761-94	6/13-9/28	37	0.0	1.6	3.2	3.1
Boyce Thompson	Dasibi	2645	5/17-7/16	16	0.5	3.0	6.5	- 5.5
	Dasibi	2646	5/17-6/12	6	-3.8	4.2	4.3	-12.0
	Dasibi	4097	6/17-7/26	9	-1.4	3.1	4.7	- 7.5
	Dasibi	2328	5/17-7/26	11	-0.4	2.6	5.2	- 6.0
	Mon. Labs	331	4/26-10/09	35	-0.3	2.2	4.0	- 4.5
	TECO	9909-113S	5/01-10/09	35	-3.9	4.5	4.9	-12.6
	TECO	8433-100S	6/19-10/08	19	-2.8	3.3	3.6	- 9.2
	TECO	8432-100S	6/19-8/28	14	-2.6	4.3	5.9	-11.1
	TECO	9896-113S	6/19-10/08	18	0.0	3.7	7.3	- 7.2
Raleigh	Bendix/O_3	006753	5/06-10/22	31	-4.1	5.4	6.4	-14.7
	Bendix/O_3	071584	5/06-10/22	32	-1.6	7.8	13.7	-16.8
	Bendix/O_3	145521	5/31-10/31	27	-0.4	8.4	16.1	-16.8
	Bendix/O_3	032759	5/30-10/31	29	-1.4	8.4	15.2	-17.9
Shafter	Dasibi	1183	3/26-10/07	33	-2.3	0.9	-0.6	- 4.1
	Dasibi	1120	3/26-10/07	33	-1.5	0.7	-0.1	- 2.8
	Dasibi	1140	3/26-10/07	21	1.0	1.0	3.1	- 1.0
	Dasibi	1907	6/13-8/13	11	1.0	0.8	2.5	- 0.5

efficiency value. Mean percent efficiencies for teflon lines used in monitoring ozone in treatment chambers at each site (Table 4.4.3.) ranged from 71 to 100. Lower efficiencies of 71 to 78 during the first third of the soybean study at Argonne were the result of using PTFE teflon lines. Higher efficiencies (83 to 90) were measured for the remainder of the study after a switch was made to FEP teflon. Only FEP teflon was in use at the other sites.

4.4.2. Biological

This report summarizes the fifth year of results for NCLAN's Biological Quality Assurance Plan (BQAP). A systems evaluation for adherence to QA protocols was made at each site between 22 July and 14 August.[1] An evaluation of QA procedures and uniformity across sites was made with recommendations to improve data comparability. The report indicated all significant items outlined in QA protocols were being followed. Comments made in the report were "to improve a good program." The detailed report is on file with the NCLAN QAO in Corvallis.

A summary of checks for weight measurement accuracy, presented in Table 4.4.4., indicates all station weights were within 1 percent of their true weights at least 99 percent of the time. Three of the four stations were always within 1 percent of the true weight.

A summary of checks for leaf area measurement accuracy, shown in Table 4.4.5., indicates measurements at three of four sites were always within 5 percent of the actual leaf area. A malfunctioning instrument in the early season caused the reduced accuracy at Argonne.

All sites are in compliance with NCLAN QA documentation requirements. The NCLAN QAO will work with the BQAP for each station in 1986, making necessary additions and updating the BQAP.

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[1] Evaluation conducted by Jeffrey C. Sprenger, QA Coordinator, Northrop Services, Inc., Corvallis, Oregon, under Support Contract Technical Directive No. AP-12-03-85.

Table 4.4.3. Mean percent efficiencies for O_3 monitoring system lines by site and study in 1985.[a]

Line #	Argonne			BTI	Raleigh		Shafter
	Corn[b]	Soybean[c]		Forage[d]	Forage[e]	Cotton[f]	Alfalfa[g]
1	87	73[h]	83[i]	94	96	93	98
2	87	76	87	92	85	91	99
3	84	76	89	96	91	86	96
4	87	75	87	95	90	89	93
5	88	76	88	96	90	89	98
6	89	75	87	93	86	87	99
7	87	78	89	95	93	91	95
8	89	76	86	94	86	87	94
9	88	77	88	98	87	90	94
10	89	76	88	92	92	87	98
11	90	75	85	97	92	93	98
12	87	71	87	100	84	86	96
13	89	73	89	95	85	93	99
14	88	71	87	95	93	90	99
15	89	74	88	99	84	88	100
16	88	73	89	96	87	91	--
17	89	72	89	97	85	89	--
18	89	73	88	98	87	92	--
19	88	76	89	97	82	88	97
20	88	74	90	88	87	92	95
21	87	73	89	94	84	90	--
22	88	72	89	96	83	92	93
23	87			95	85	91	98
24	87			94	86	90	97
25	88			97	87	94	98
26	86			95	84	92	99
27	86			96			96
28	88			92			97
29	86			97			95
30	88			98			
31	88			93			
32	87			98			
33	87			93			
34	87			89			
35	86			98			
36	86			96			
37	88						
38	87						
39	87						
40	87						
41	87						
42	87						

Table 4.4.3 (cont'd)

(--) Indicates no line in use.

[a] Instrumentation differences factored out.

[b] Average of 3 to 21 sample line checks.

[c] Left column average of 4 to 6 checks; right column average of 4 to 14 sample line checks.

[d] Average of 4 to 6 sample line checks.

[e] Average of 4 sample line checks.

[f] Average of 3 sample line checks.

[g] Average of 30 sample line checks.

[h] This column contains efficiencies for PTFE teflon lines in use 6/23-8/1.

[i] This column contains efficiencies for FEP teflon lines in use 8/2-9/29.

Table 4.4.4. Summary of QA checks for weight measurements.

Location	Total # Days Checked	Total # Calibration Checks	Mean % Accuracy	Deviation Range %[a]	% ≥ 99% Accurate
Argonne	24	361	99.95	+1.00 -1.00	100.0
Boyce Thompson	5	41	99.97	+0.10 -0.10	100.0
Raleigh	83	962	99.89	+1.00 -2.00	99.9
Shafter	14	96	99.98	+0.10 -0.00	100.0

[a] Percent deviation range from 100%.

Table 4.4.5. Summary of QA checks for leaf area measurements.

Location	Total # Days Checked	Total # Calibration Checks	Mean % Accuracy	Deviation Range %[a]	% ≥ 95% Accurate
Argonne	5	52	98.27	+1.81 -10.22	90.4[b]
Boyce Thompson	23	50	99.16	+0.22 - 0.20	100.0
Raleigh	14	273	99.69	+2.02 - 0.48	100.0
Shafter	3	13	99.47	+1.15 - 1.37	100.0

[a] Percent deviation range from 100%.

[b] Accuracy reduced in early season due to corrosion found in instrument about mid-season. After repair, all readings were at least 97% accurate.

SECTION 5

DATA SYNTHESIS AND ANALYSIS PROGRAM
(SERCLAP) -- V.M. Lesser, J.O. Rawlings, S.E. Spruill, M.K. Nations

5.1. Introduction

Future focus of this project is the coordinated analysis of all NCLAN data. Five general types of analyses have been discussed which are outlined in the remainder of Section 5.1. Two of these topics have been investigated in more detail, these reports are included as Sections 5.2. and 5.3. in this chapter. Further analyses will be the major emphasis of this program for the current year. Table 5.1.1. details the quality assurance procedures for the NCLAN Data Library.

5.1.1. Alternative Dose Metrics

This dose metric concept incorporates the idea of the power-weighted mean presented at the January 1986 NCLAN workshop. For the Raleigh 1982 and 1983 studies, alternative dose metrics were investigated which brought the dose response curves for the different types of O_3 dispensing methods into the closest agreement. The intention is to extend the investigation of alternative dose metrics to include time of day and seasonal weighting. The weighting will use some environmental measure which might serve as a surrogate measure of "plant activity". The hypothesis is that the "effective dose" of O_3 is directly related to plant activity. The criterion we will use to measure effectiveness of alternative dose metrics is, as before, the degree of concordance of the response curves from different studies.

The data sets we anticipate using are, by species, those which have been tested in different sites and/or years or have moisture stress as a factor (e.g., soybean, wheat, cotton, corn, forage). A preliminary analysis of the Raleigh 1982 Soybean (28) and 1983 Tobacco (29) data was reported at the workshop and is included in this report as Section 5.2.

5.1.2. Completion of Weibull Functions, Test Model Assumptions and Investigation of Alternative Response Models

This series of analyses includes the following:

a. Development of final dose response functions for all data sets using 7 hr and/or 12 hr O_3 means.

b. Investigate basic model assumptions: homogeneity of variance, normality, and adequacy of models.

c. Investigate other models, modifications of the Weibull model, or methods of analysis to take into account any inadequacies observed in the models produced.

In order to meet the needs of the economic assessment, final regional and national dose-response prediction equations will be developed for all crops. This will involve compressing the dose-response information into a

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Table 5.1.1. Quality assurance procedures - NCLAN Data Library.

A. The following procedures are followed with data received for this project to assure the data filed are accurate:

   1. A hard copy of all biological data (Data Sets III) is sent to the principal investigator for his/her verification.

   2. For the Air Quality data sets:

      a. If the data are directly entered by this project (i.e., keypunched at NCSU), a hard copy of that data is sent to the principal investigator for verification.

      b. If the data are transferred by tape or by punch cards to Raleigh, a copy of the first 100 observations is sent to the principal investigator for verification. Data transferred by these methods are quite accurate; this check verifies our formatting of the data.

   3. A calendar is kept to indicate:

      a. Date an experiment is complete and filed in Data Library.

      b. Date when data are sent to principal investigator for verification.

      c. Date the final copy of data, which has been verified by the principal investigator, has been filed into Data Library.

B. The following analyses are carried out on the following data sets for each experiment.

   1. Descriptive Information - Data Set I.

      This data set, containing the description of the experiment, is sent to the principal investigator for verification.

   2. Air Quality Data - Data Sets II.

      For the data sets included in this category of data, the following analyses are conducted and sent to the principal investigator for verification. Data are filed into the library after final approval has been given by the principal investigator.

      a. The amount of missing data is calculated for both non-dispensing and dispensing times over the entire dispensing season by treatments. This is compared with those percentages listed in the Annual Reports, if that information is reported.

Table 5.1. (cont'd)

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b. Simple statistics are calculated on both the 7-hr and 24-hr data sets. These statistics include means, number of observations, maximum and minimum values. Univariate procedures are also conducted to pinpoint any outliers. The means and peak values are compared with those values given in the Annual Reports.

3. Plant Response Data - Data Sets III.

For all data sets included in this category, the means are calculated and compared with those given in the Annual Reports.

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minimum number of prediction equations. All homogeneous sets of responses will be represented by a common dose-response equation with the parameters of the model changing for different situations. As data are combined over experiments to obtain final dose-response models, the validity of the model assumptions will be checked. The assumptions have been checked for the combined Raleigh soybean data, 1981-1984, which was reported at the workshop and is included in this report as Section 5.3. From the results on these data, an alternative dose response model, a logarithmic version of the Weibull model, was developed to more nearly satisfy the basic assumptions. These analyses will be extended using all soybean data and will be developed for each species where data can be combined over sites and/or years.

5.1.3. Incorporation of Experiment-to-experiment Variability in Measures of Precision of Regional Predictions of Yield Loss.

When extending dose-response models over sites and years, the additional component of variability due to "environment x O_3" interaction should be included in the estimate of error. This interaction variance contributes to the degree of uncertainty in regional predictions. Adequate information is not available to properly assess the magnitude of this source of uncertainty, but it is important that the degree of confidence in the predictions be as clearly defined as possible. This component of the data synthesis project will examine the question of degree of confidence in regional predictions. We hope to place some bounds on the degree of confidence by examining the repeatability of results from similar NCLAN experiments done in different sites and/or years.

5.1.4. Analysis of Unbalanced Data and Correlated Errors.

Combining data over several experiments results in a correlated error structure. When the data are balanced, the correlated error structure is taken into account in the conventional analyses of variance. However, the correlated error structure causes problems in the analysis of unbalanced data and the estimation of the parameters for nonlinear models. Further development of methods of data analysis and testing of hypotheses is needed for unbalanced data when nonlinear response models, like the Weibull, are being used. This project will investigate other methods of analysis that more properly take into account the correlation structure.

5.1.5. Optimal Experimental Designs.

The optimum choice of treatment dosage levels for prediction of relative yield losses from O_3 is being investigated.[1] The research assumes a Weibull dose response curve and 24 exposure chambers. The optimum design for estimation of the Weibull parameter is three distinct dose levels with equal replication at each dose level. The three optimum dose levels have been determined for estimation of the Weibull model parameters and are dependent on prior estimates of the parameters. More than three distinct points are needed for protection against "misguessing" the Weibull parameters and to allow for testing adequacy of the model. Relative efficiencies of four- and six-point designs for estimation of the Weibull parameters and predicted relative yield losses for given shifts in O_3 level are being determined.

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[1] Part of the Ph.D. thesis research of Karen Dassel, Statistics Department, N.C. State University.

5.2. Investigation of Alternative Dose Metrics

5.2.1. Introduction

The National Crop Loss Assessment Network (NCLAN) is composed of several research groups cooperating to assess the economic impact of ozone (O_3) on crop production. To obtain these economic assessments, dose response relationships between the yield of major agricultural crops and O_3 have been investigated. Experiments have been conducted since 1980 at four to six sites across the country; similiar experimental designs and methods are followed at each site. The Data Synthesis and Analysis Project was developed to archive the NCLAN data and to allow a coordinated analysis of all data over all sites and years. Currently, data from all sites are being compiled in Raleigh, NC and initial analyses have begun, using data from the Raleigh site.

This analysis is designed to investigate the usefulness of alternative dose metrics on the dose response models. During the initial years of NCLAN, plants were exposed to variations in O_3 levels over a 7-hr period (1000-1700 DT). The 7-hr mean averaged over the exposure period of the growing season was used as the O_3 exposure metric in the dose-response relationships. In these earlier NCLAN experiments, O_3 was added at a constant rate to ambient air. Presently, O_3 is added in an amount proportional to the ambient air concentration and exposures are for a 12-hr period (0800-2000 DT). The 12-hr mean averaged over the exposure season is the dose metric currently being used for these dose response models.

The objective of the dose metrics study is to investigate the usefulness of alternative methods of averaging the ozone exposure. Conceptually, a properly defined dose would reflect the effective dose received by the plant and give more consistent dose response models over a variety of exposure regimes. The alternative dose metrics being considered result from differential weighting of the hourly O_3 readings according to three different criteria: 1) relative weighting of peak vs non-peak exposures, 2) weighting with respect to time of day of exposure, and 3) weighting with respect to time of growing season. It is conceivable that the last two weighting criteria could be incorporated into a single weighting by using an environmental measure that is correlated with level of plant activity at the time of exposure (i.e., a temperature or radiation weighting function).

The Raleigh site has two studies (28,29) where 7-hr constant and 7-hr proportional methods of O_3 addition were applied concurrently in the same experiment. One of these experiments also compared a 7-hr vs a 12-hr O_3 exposure period. This presentation addresses the impact of the first two weighting criteria. The two Raleigh studies were not designed to test alternative dose metrics and therefore are not powerful designs to distinguish the alternative dose metrics. The results are to be interpreted as indications that merit further study.

5.2.2. Materials and Methods

The two Raleigh experiments were conducted during the summers of 1982 (28) and 1983 (29) at the SERCLAP NCLAN site, located 8 km south of Raleigh, NC. The objectives of both studies include a comparison of the effects of the proportional and constant methods of O_3 addition. For the 1982 study, the impact of the constant and proportional 7-hr O_3 additions on soybeans (Glycine max. L. Merr. cv. 'Davis') were determined. Open top chambers were utilized, as described in previous NCLAN experiments, with O_3 dispensed from 1000-1700 hr EDT from 20 July to 17 October. There were eight chambered O_3 treatments in each of two randomized complete experimental blocks. The treatments consisted of charcoal filtered air (CF), nonfiltered air (NF), and the added O_3 treatments. The constant addition O_3 treatments consisted of 0.02, 0.04, and 0.06 ppm of O_3 added to NF. The proportional addition O_3 treatments consisted of 1.3, 1.6, and 1.9 times the amount of O_3 present in ambient air.

In 1983, the impact of 7-hr vs 12-hr O_3 exposure was investigated in addition to comparing the effects of the constant and proportional 7-hr O_3 addition. Exposures on flue-cured tobacco (Nicotiana tabaccum L. cv McNair 944) began on 2 June and continued through 22 August. Two of the chambered O_3 treatments were CF and NF (no additional O_3 added). Three constant addition O_3 treatments were 0.015, 0.030, and 0.045 ppm of O_3 to nonfiltered air. The proportional treatments added O_3 at a rate of 1.3, 1.5, and 1.8 times the O_3 present in ambient air. The three proportional O_3 treatments were run under both a 7-hr (1000-1700 hr EDT) and a 12-hr (1000-2200 hr EDT) exposure day.

The differences in the exposure treatments of these two studies provide the basis for comparing alternative dose metrics. The proportional dispensing causes the frequency distribution of the hourly O_3 readings to be more variable than the constant; hence, an opportunity to compare constant weighting of O_3 levels with differential weighting of peaks. The additional 5 hr of exposure allows a comparison of constant weighting with respect to time of day with differential weighting of the first 7 hr and the last 5 hr.

Analyses of each year's data did not find any significant difference among the methods of O_3 addition. For the 1982 study the dose metric used to compare these methods was the 7-hr seasonal mean. For the 1983 study, both the 7-hr and 12-hr seasonal means were used. In order to investigate alternative dose metrics, several power weighted dosages were calculated. A general weighted average of O_3 exposures can be written as:

$$\frac{\Sigma w_i x_i}{\Sigma w_i}$$

where the w_i are the weights and x_i are the hourly O_3 concentrations. If weighting is to be proportional to the concentration so that peaks get relatively more (or less) weight, the weights can be set equal to a power of the concentration, i.e. $w_i = x_i^p$. Thus, the power weighted mean becomes

$$\overline{W}(p) = = \frac{\Sigma x_i^{p+1}}{\Sigma x_i^p} \qquad (1)$$

where: p = power weight
x = hourly ozone concentration
i = i^{th} observation, then Σ (summed) over all observations (n) in exposure period.

With p = 0 the denominator becomes the number of observations, and $\overline{W}(o)$ is the simple arithmetic average of the O_3 exposures. Larger values of p give greater relative weight to the peaks; smaller values of p give less relative weight to the peaks. The power weighted O_3 dose metric was calculated for powers (p) ranging from -0.5 to 4.0.

The effect of the power weighting is illustrated using a simple example. Consider two samples, each with 10 observations: sample 1 has x ranging from 0.01 to 0.10 ppm in steps of 0.01 units, while sample 2 has x ranging from 0.0325 to 0.0775 ppm in steps of 0.005 units. Sample 1 might represent the relatively greater dispersion of proportional exposure and sample 2 the lesser dispersion of constant exposure. Both samples give the same mean of 0.055 ppm. A plot of these O_3 values for these 10 steps is shown in Figure 5.2.1. The power weighted means for the two samples for several choices of p are shown in Table 5.2.1. Sample 1, the sample with the greater dispersion, gives the greater shift in the power weighted means. Note that with p=4, the power weighted mean is within 15% of the peak reading in both cases.

To restate our objectives, the intent of this exercise is to choose the power weighted mean and the relative weighting of the 7-hr and 5-hr daily time periods which cause the response curves for the different methods of dispensing to be most similar. This is based on the premise that any differences in the observed response curves are due to the effective dose to the plant being different from the current dose metric. Thus, the 'proper' weighting should cause the response curves to be similar for the different dispensing methods. Weibull regression models were developed relating total plant yield to the different power weighted dose means. Tests were conducted to compare the homogeneity of the dose-response curves for the dispensing methods in 1982 and 1983. In those models which fit a common response over all methods of O_3 addition, the residual sums of squares were compared. A three-parameter Weibull model

Table 5.2.1. Examples of power weighting on two types of ozone distributions.[a]

	P values						
Sample[b]	-0.5	0	0.5	1	2	3	4
1	.045	.055	.064	.070	.079	.084	.087
2	.053	.055	.057	.059	.062	.065	.067

[a] Sample 1 had values of O_3 ranging from 0.01 to 0.10 ppm and sample 2 ranged from 0.033 to 0.078 ppm.

[b] A p=0 gives the simple arithmetic average of the ozone exposures.

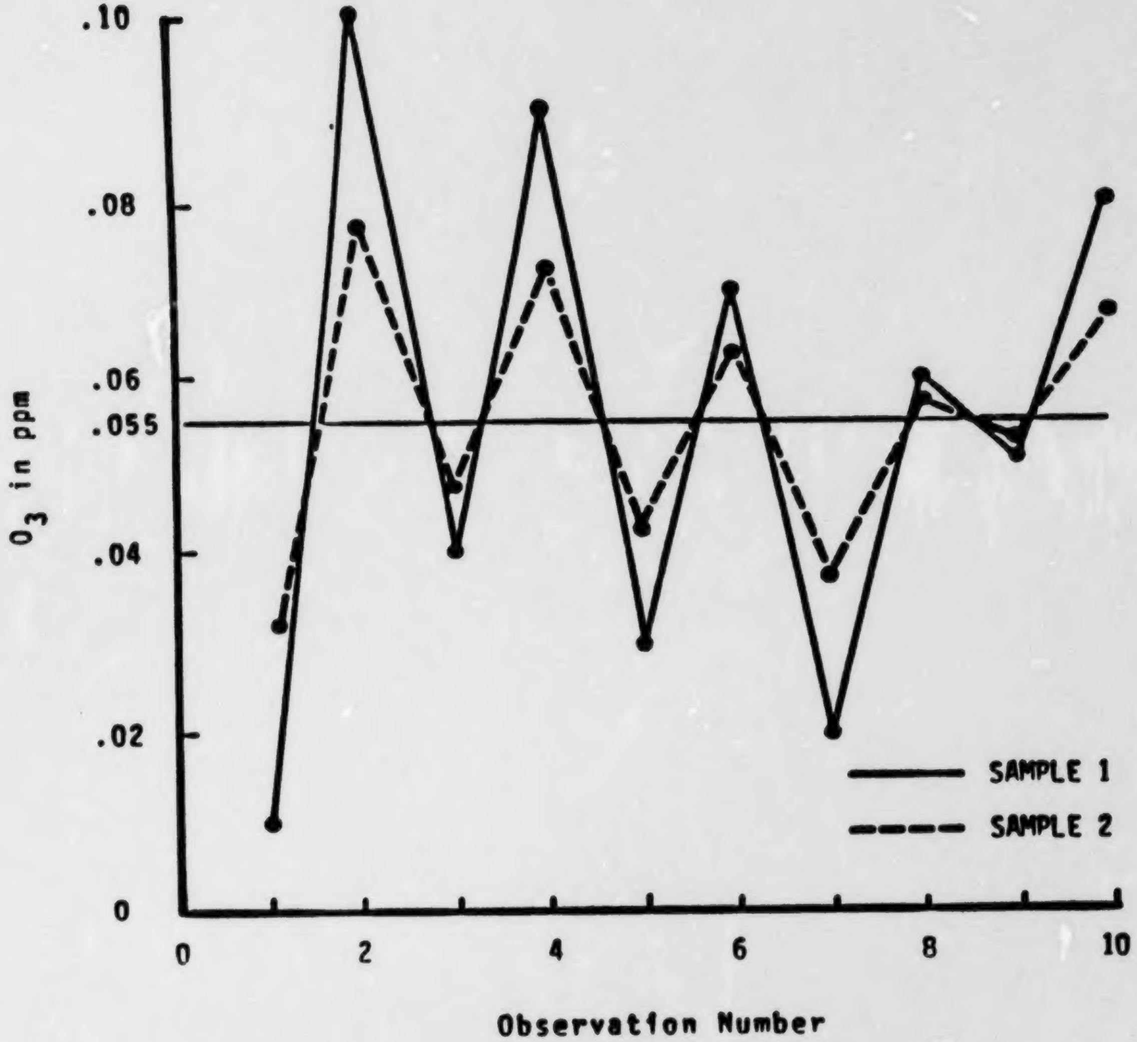

Figure 5.2.1. Expected range of O_3 levels for a proportional (Sample 1) and constant (Sample 2) method of O_3 addition.

was fit to the data using each of the power weighted dose metrics. The dose metric which brought the response for the different dispensing methods into closest agreement, as reflected in the smallest residual sum of squares, can be interpreted as the dose metric most nearly reflecting the plants' reaction to O_3.

For the 1983 study, the effect of the additional 5-hr O_3 period was also investigated. To obtain this dose metric, the 7-hr and 5-hr power weighted means were first calculated and then different relative weights ranging from 7:5 to 12:0 were applied to each of these components to produce the 12-hr dose metric. Thus, $p=0$ and relative weights of 7/12 and 5/12 for the 7-hr and 5-hr periods gives the conventional 12-hr average. Again, the dose metric giving the minimum residual sum of squares would be regarded as the most appropriate dose metric. In addition, the relative weights for the 7-hr and 5-hr periods were estimated directly from least squares by incorporating the weight as another parameter in the Weibull model. For comparison with the Weibull model, the 7-hr:5-hr weighting for a linear response model was also estimated.

5.2.3. Results

As p increases, more emphasis is placed on the higher peaks in calculation of the seasonal O_3 dose. For similar O_3 levels among the constant and proportional methods of addition, increasing p results in higher O_3 means for both methods. Since the proportional method of dispensing creates greater dispersion, larger values of p produce relatively higher seasonal O_3 means for proportional than for constant addition. Table 5.2.2. shows this using the 12-hr power weighted mean.

Each of the power weighted means was used as the dose metric in fitting the Weibull dose response models (the smallest residual sum of squares). When a common Weibull was forced onto all dispensing methods the smallest residual sum of squares was obtained at $p=1$ for the 1982 study as shown in Table 5.2.3. For $p \geq 2$, the response curves for the different dispensing methods were significantly different from each other. The 1982 study used the 7-hr averaging. For the 1983 study, the power weighted means based on the 7-hr averaging period gave a minimum residual sum of squares when $p=0$. The 12-hr averaging period, however, gave a minimum residual sum of squares when $p=1$, the simple 12-hr mean (Table 5.2.3). There was significant heterogeneity among the response curves for $p \geq 2$ when the 12-hr averaging period was used. As shown for both studies, the residual sum of squares (for the common Weibull) increased with higher values of p to the point that the curves, in fact, became significantly different. A plot of these curves using the 12-hr mean in the 1983 study for two values of p, (0 and 4), is shown in Figure 5.2.2.

Finally, the joint consideration of 7-hr versus 5-hr weighting and power weighting of O_3 for the 1983 experiment gave the results in Table 5.2.4. The minimum residual sum of squares from the Weibull models for each value of p is underscored. The optimum weighting for the 7-hr versus 5-hr periods is either 10:2 or 11:1, depending on p. Note that this gives relatively more weight to the 7-hr period than does the simple 12-hr

Table 5.2.2. Twelve-hour power weighted ozone means for tobacco study, 1983. Differential weighting of dose ranging from P=-.5 to power four weighting (P=4).[a]

TRT[b]	P=-.5	P=0	P=2	P=4
CF	0.0231	0.0276	0.0350	0.0467
NF	0.0445	0.0520	0.0614	0.0720
C15 (7)	0.0538	0.0651	0.0779	0.0931
P1.3 (7)	0.0543	0.0676	0.0850	0.1082
P1.3 (12)	0.0714	0.0835	0.0984	0.1164
C30 (7)	0.0584	0.0723	0.0887	0.1073
P1.5 (7)	0.0591	0.0762	0.1006	0.1325
P1.5 (12)	0.0802	0.0963	0.1151	0.1360
C45 (7)	0.0634	0.0812	0.1025	0.1240
P1.8 (7)	0.0643	0.0864	0.1198	0.1593
P1.8 (12)	0.0930	0.1136	0.1371	0.1625
AA	0.0574	0.0630	0.0706	0.0813

[a] Concentrations were also computed for P=1 and P=3. These values follow the increasing patterns as shown in the above data and thus were not presented.

[b] Treatment designations: CF = charcoal filtered air, NF = nonfiltered air, AA = ambient air. C15, C30, C45 = constant additions of O_3 at 0.015, 0.030, and 0.045 ppm respectively. P1.3, P1.5, P1.8 = proportional addition of O_3 at a rate of 1.3, 1.5, 1.8 times the current ambient air reading, respectively. The dispensing hours in a day (7 = 1000-1700 hr EDT and 12 = 1000-2200 hr EDT).

Table 5.2.3. Residual sums of squares from Weibull models for the 1982 and 1983 studies. The differential weighting on dose ranged from P=0[a] to P=4.

P	1982 7-hr Mean	1983[b] 7-hr Mean	1983 12-hr Mean
0	18498	5154	7852
1	16378	6146	6329
2	18872	6811	6695
3	21161	7250	7149
4	26879	7577	7452

[a] Proportional weighting was applied to the 7-hr (1982 and 1983) and the 12-hr 1983 data sets.

[b] Values for the 1983 study for p=0, 1, and 2 are repeated in Table 4 to demonstrate the joint effect of time of day weighting.

Table 5.2.4. Residual sums of squares from Weibull models using six power weighted means over different weights of the 7-hr:5-hr proportion of the 12-hr mean for the 1983 study.

Proportion[a] 7-hr:5-hr	P=-1	P=-0.5	P=0	P=0.5	P=1	P=2
7:5 (12-hr mean)	6561	7172	7837	8169	8364	8565
8:4	5535	5975	6656	7059	7322	7644
9:3	5098	5186	5799	6250	6573	7008
10:2	5074	4775	5272	5757	6131	6663
11:1	5311	4696	5069	5579	5992	6598
12:0 (7-hr mean)[b]	5697	4881	5154	5685	6125	6777
Nonlinear[c] estimate	9.55: 2.45	10.76: 1.24	11.18: 0.82	11.10: 0.90	10.98: 1.02	10.74: 1.26

[a] Varying relative weights on the 7-hr and 5-hr power weighted seasonal mean were used to calculate the 12-hr weighted seasonal mean. The proportions listed were multiplied by the respective 7-hr:5-hr seasonal means, summed, and then divided by 12. The underscored number shows the smallest residual sum of square for that value of p.

[b] The weight 12:0, no weight given to the 5-hr mean, results in the 7-hr mean.

[c] The nonlinear estimates of the time proportion for each of the power doses obtained for p=-1 to p=2.

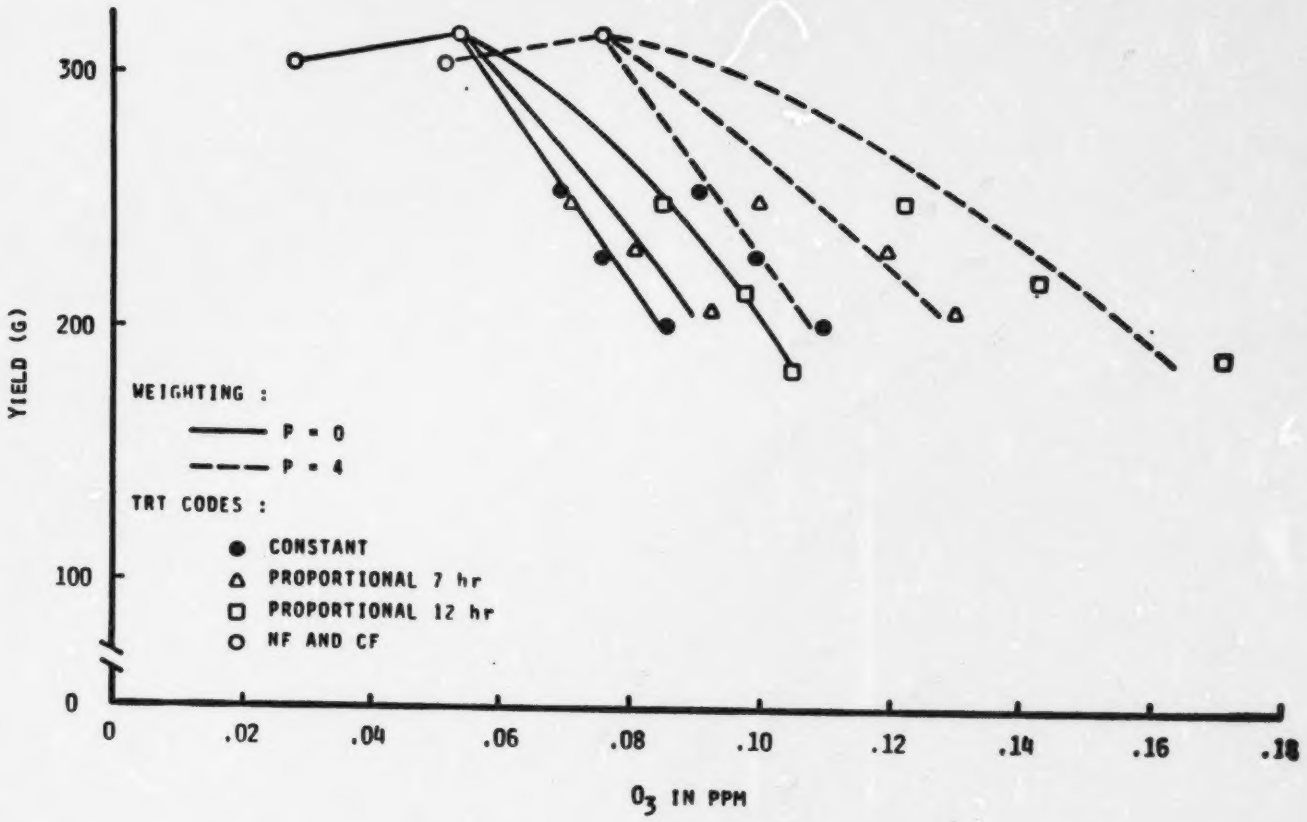

Figure 5.2.2. Change in estimated tobacco yield to two types of O_3 calculation (12-hr average for P=0 and 4) for three types of O_3 addition.

averaging. This suggests that the final 5-hr time period is important in the plants response to O_3 but not as important as the 7-hr in the middle of the day. The minimum residual sum of squares in the entire table occurs at $p=-0.5$ and 11:1 weighting. This residual sum of squares is only slightly lower than the 5069 obtained with $p=0$ and 11:1 weighting. In Table 5.2.5., the results of the linear response model for $p=0$ and 1 is compared with the Weibull model. The ratios of the 7-hr to 5-hr periods found for the polynomial are very similar to those shown for the Weibull.

5.2.4. Discussion

Changes in the fit of the dose response models for the different measures of O_3 addition indicate the effect of alternative dose metrics. The 1982 study using the 7-hr O_3 averaging period showed that a power weighted mean with $p=1$ gave the best Weibull fit among the power weights used. For the 1983 data, the best fit Weibull model was found at $p=0$ for the 12-hr mean and at $p=0.5$ for the 7-hr mean. If the 9:3 weight is given to the 7-hr:5-hr period, a $p=-0.5$ resulted in the best fitting model. Weighting the components of the 7-hr to 5-hr dose suggests that the last 5 hours of exposure have an impact on tobacco yields but that they should not be weighted as heavily as the 7 hours in the middle of the day when, presumably, the plants are more active.

The dose metric of present NCLAN studies are based on a $p = 0$ (equal weight). The dose metric results indicate the dose measures used in NCLAN correspond closely with the results found in this dose metric study. The dose measures studied used differential weighting on both time of day and the magnitude of the O_3 concentration. The relationship of O_3 to the stage of plant growth, mentioned in the introduction, is another factor to be investigated. Experiments need to be designed specifically to address the most appropriate measurement of dose.

5.3. Investigation of Basic Model Assumption

5.3.1. Introduction

The 1981-1984 soybean data from Raleigh (21,26,27,28) is the largest set of experiments with a single species in the NCLAN studies. The data from these studies provide a reasonable analysis of residuals. The purpose of this study is two-fold: 1) to determine if the residuals analysis provides an indication of whether or not the basic assumptions of our analyses are met (normality and homogeneous variances); 2) to determine if the question of relative risk of crop yields for different levels of O_3 can also be addressed from the analysis of residuals. Risk is referred to as a measure of uncertainty associated with the predicted yields of the dose response models. Higher (or lower) risk with increasing O_3 levels would be reflected in corresponding shifts in the dispersion of the residuals.

5.3.2. Materials and Methods

The 1981 and 1982 studies used four quadrants per chamber for yield determination, while the 1983 and 1984 studies used only one pair

Table 5.2.5. Comparison of power weighting results from both the Linear and Weibull models.

	Linear			Weibull		
	P=-5	P=0	P=1	P=-.5	P=0	P=1
β_1[a/]	-1528	-1393	-1186	-	-	-
β_2	- 201	- 119	- 111	-	-	-
RSS[b/]	6115	5832	6251	5064	5992	4688
Proportion[c/]	10.60: 1.40	11.06: 0.94	10.97: 1.03	11.18: 0.82	10.98: 1.02	10.76: 1.24

[a/] The β represent the regression parameters estimated in the model:

$$Y = \beta_0 + \beta_1(7\ h\ O_3\ mean) + \beta_2(5\ h\ O_3\ mean)$$

[b/] RSS is the residual sum of squares.

[c/] The estimates of relative weights for 7-hr and 5-hr exposure periods.

(northern) of quadrants. Since plot size affects residual variances, the data from 1981 and 1982 were subdivided so that the north pair of quadrants was used as one data set and the south pair of quadrants as another. Thus, all analyses are based on the chamber means, using two quadrants of data per chamber. In addition, the 1983 and 1984 data were split with respect to moisture stress levels. This gave a total of eight data sets.

The appropriate analysis of variance was run on each data set. The eight error variances and the residuals, Y - Yhat, (where Y = observed dependent variable and Yhat = predicted dependent variable), for each data set were computed and used in the subsequent residuals analyses. There were a total of 174 residuals and 80 degrees of freedom from the eight data sets for the combined residual sum of squares. There is some heterogeneity of variance, introduced by least squares arithmetic, and lack of independence which is being ignored in the residuals analysis done in this study.

Tests of heterogeneity of the error variances from the eight sets of data were conducted using Bartlett's Chi-square test. This tests heterogeneity of variance only from one data set to another; it will not detect heterogeneity of variance within data sets. The residuals from all eight data sets were plotted against the predicted yield, Yhat, and against the level of O_3 to see if there was any tendency for dispersion to increase or decrease with the mean yield or with the level of O_3. For example, a fan-shaped pattern of residuals when plotted against Yhat suggests an increasing variance of the residuals. A normal plot of the residuals, which is the ordered residuals plotted against the normal order statistics for the particulate sample size, was used as a visual check on normality. If the residuals are normally distributed, the normal plot should give a straight line except for sampling error.

Fan shaped patterns in these residual plots led to the investigation of the cause of the heterogeneity. To determine whether the fan shape residual plots were reflecting an association of the dispersion of the residuals with the Yhat or with O_3 concentration, the absolute values of the residuals were regressed (linearly) on the Yhat and O_3 using the model:

$$|\text{Residual}| = \beta_0 + \beta_1(\text{Yhat}) + \beta_2(\text{7-hr } O_3 \text{ mean}) + \varepsilon$$

where: β_0 = intercept
β_1 = regression parameter for Yhat
β_2 = regression parameter for O_3 mean
ε = sampling error

Since yield level and Yhat are negatively correlated with O_3 dose in these data, partial plots from the regression of |residual| on Yhat and O_3 were used to help identify whether the heterogeneity of variance results primarily from the commonly observed association of the variance and the mean of a variable or from the impact of O_3 on relative sensitivity of soybeans. The partial plots show the remaining relationship between the dependent variable and the independent variable after the effect of the other independent variable has been taken into account (or adjusted for).

The results of the preceding analyses suggested that the behavior of the residuals could be improved with an appropriate transformation of yield. For this purpose, the Box and Cox general method of finding the appropriate power transformation to improve normality and stabilize the variance was used. The general transformation is:

$$Z(\lambda) = \frac{(Y^{\lambda} - 1)}{(\lambda \dot{Y}^{\lambda-1})}$$

where: $\dot{Y}$ = geometric mean of all data.
λ = power transformation on Y.
(λ = -1, -0.5, 0, 0.5, 1)

The transformed dependent variable, $Z(\lambda)$, was computed for five choices of λ and the analysis of variance of the eight data sets repeated for each choice. The maximum likelihood estimate of λ is that value of λ which gives the minimum residual sum of squares. For our purposes, we used the pooled residual sum of squares from all eight data sets and the minimum value of λ was determined graphically.

5.3.3. Results

The residual mean squares from each of the eight studies are listed in Table 5.3.1. The test of homogeneity of the eight variances using Bartlett's test did not show heterogeneous variances among the eight data sets.

A normal plot of the pooled residuals from these eight analyses of variances is shown in Figure 5.3.1. No indication of a non-normal distribution is seen in the plot. Both the residual versus Yhat plot and residual versus O_3 level plot, however, suggest larger dispersion of the residuals associated with higher yields and with lower O_3 exposure (Figures 5.3.2. and 5.3.3.). To verify that this visual perception was supported by the data, the residuals were arbitrarily grouped according to the level of O_3 and yield level. Then the square root of the average squared residual, a kind of standard deviation, was computed for each group (see horizontal scale in both Figures 5.3.2. and 5.3.3.). The plots of the 'standard deviation' against O_3 level and against Yhat show the distinct decrease in variance with increasing O_3 and increase in variance with increase in mean yield level, Figure 5.3.4. The relatively high negative correlation between yield and O_3 in these data preclude any clear interpretation of whether this is reflecting the commonly observed association of variance and mean or a decreased sensitivity of soybeans exposed to higher levels of O_3.

Table 5.3.1. Residual mean squares of soybean studies (1981-1984). Bartlett's test of homogeneity results.[a]

Experiment[b]	df[c]	RMS
1981 - N	23	3695
1981 - S	23	3926
1982 - N	7	1500
1982 - S	7	1509
1983 - A	6	3358
1983 - I	5	4466
1984 - A	5	1357
1984 - I	4	821
	Total df = 80	Pooled s^2 = 261

[a] The calculated Chi-square for Barlett's test was 7.457. The critical Chi-square at the 0.05 level with 7 degrees of freedom was 14.067.

[b] Code definition:
N = northern quadrants
S = southern quadrants
A = irrigated moisture plots
I = inadequate moisture plots

[c] df = degrees of freedom of the residual mean squares (RMS).

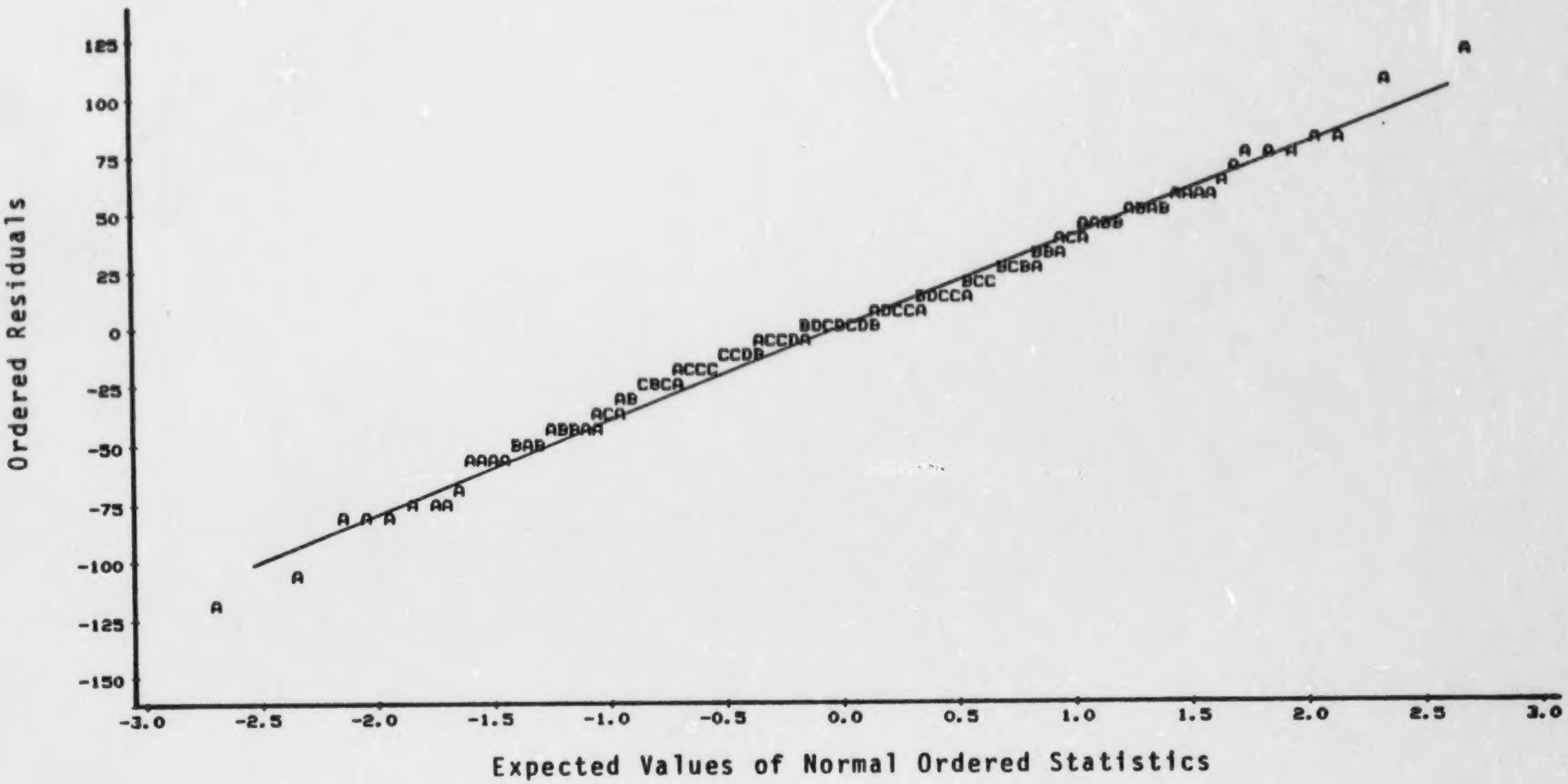

Figure 5.3.1. Normal plot of residuals from analyses of variance. Letter codes on plot refer to the number of observations at that point on the plot:

A: one observation
B: two observations
C: three observations

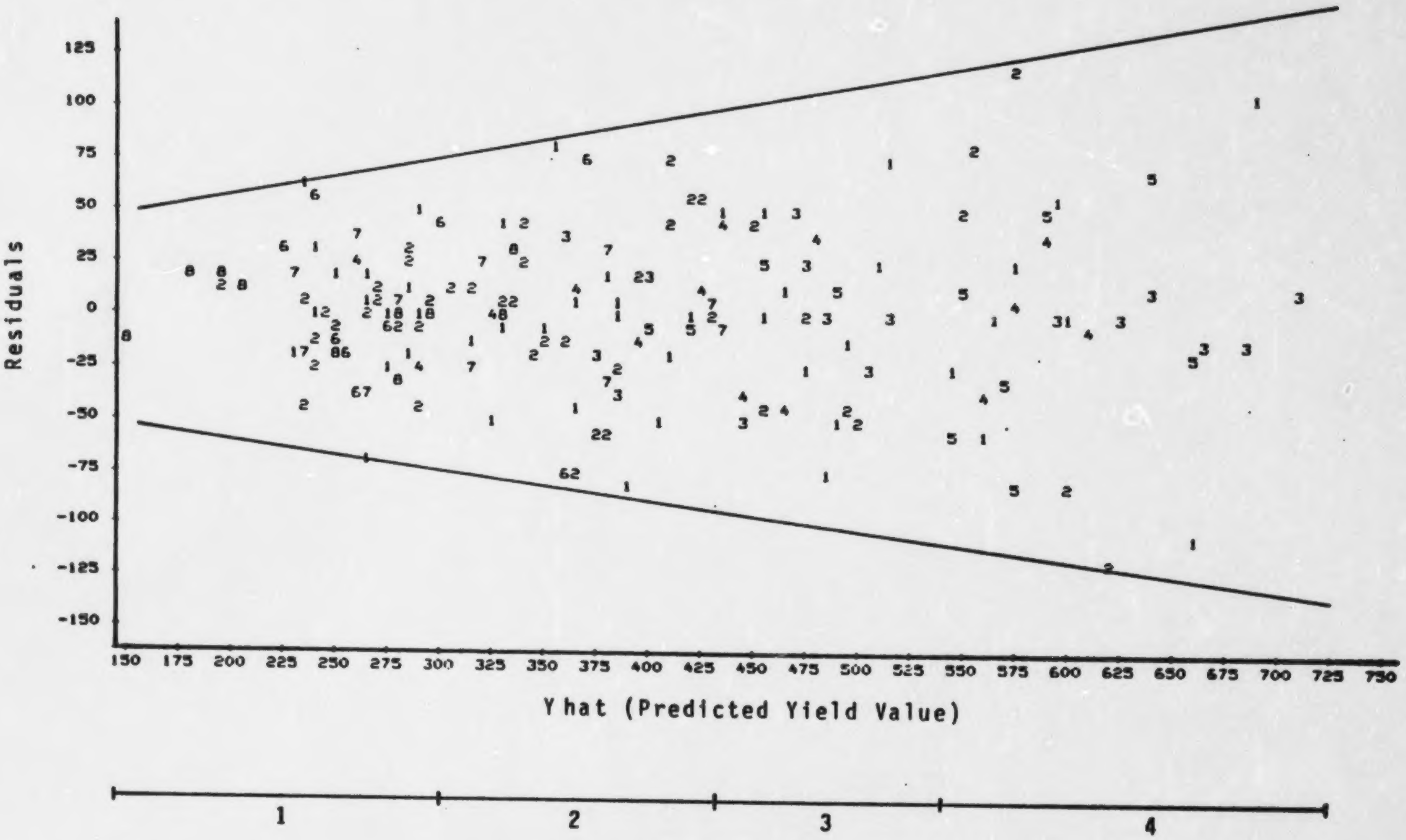

Figure 5.3.2. Residuals versus predicted values from analyses of variance. The numbers plotted on figure refer to one of eight data sets: 1 = 1981 - northern quadrants; 2 = 1981 - southern quadrants; 3 = 1982 - northern quadrants; 4 = 1982 - southern quadrant; 5 = 1983 - irrigated moisture plots; 6 = 1983 - inadequate moisture plots; 7 = 1984 - irrigated moisture plots; and 8 = 1984 - inadequate moisture plots.

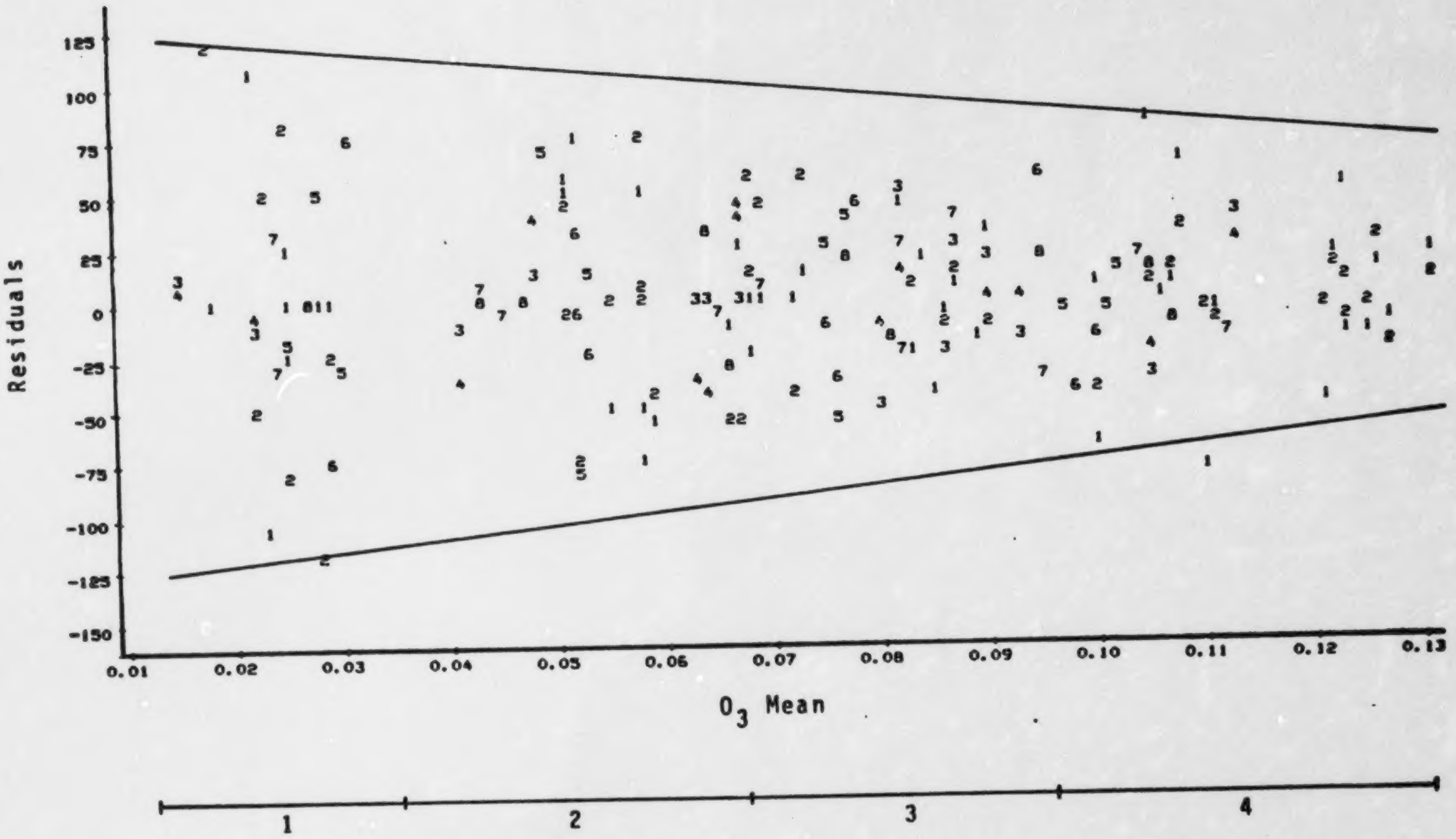

Figure 5.3.3. Residuals from analyses of variance versus 7-hr O_3 mean. The numbers plotted on figure refer to one of eight data sets (see Figure 5.3.2).

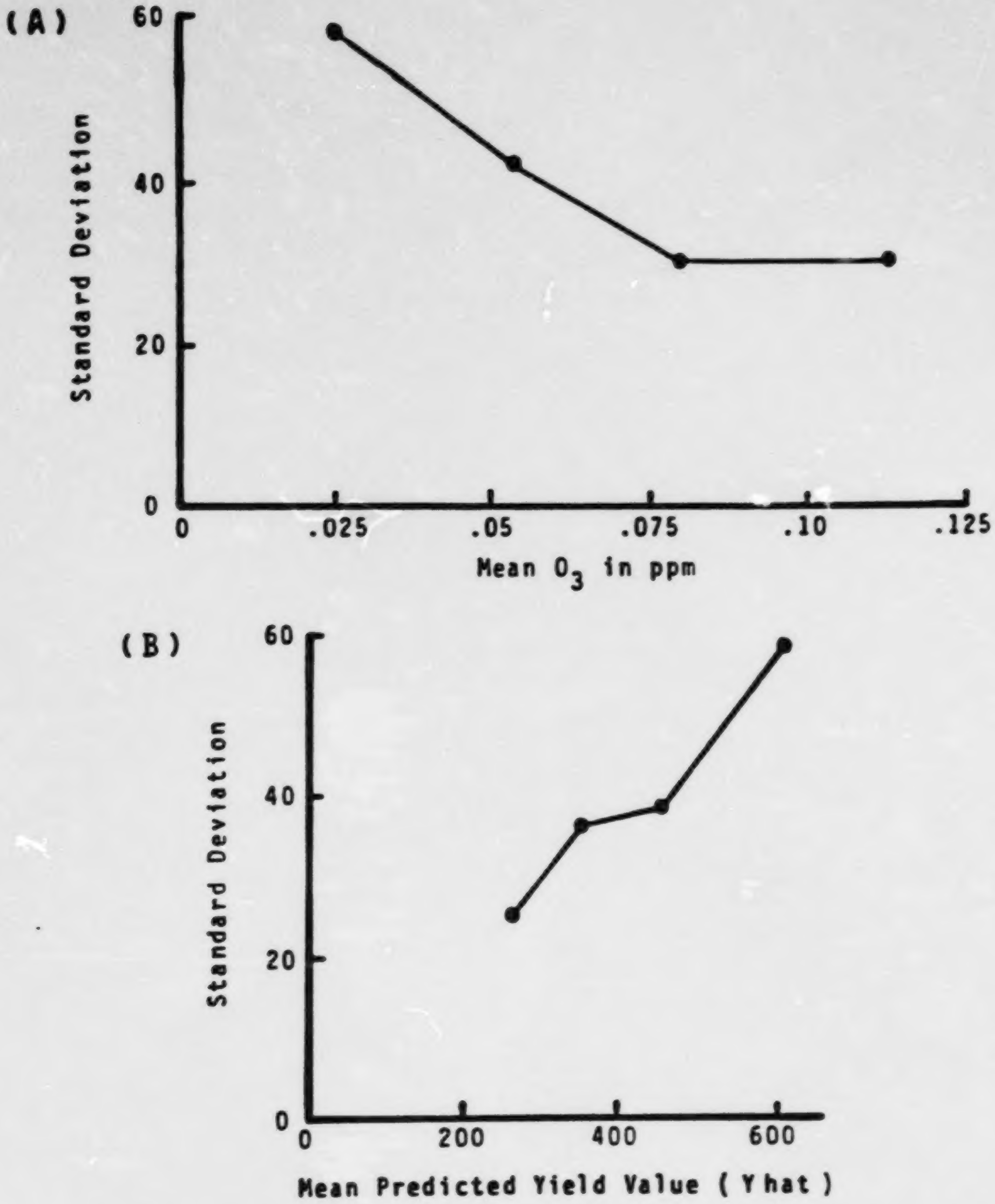

Figure 5.3.4. "Standard deviation" vs 7-hr O_3 mean (A) and vs Yhat (B) of the four groups chosen from Figures 2 and 3.

The linear regression of the absolute value of the residuals on Yhat and O_3 level showed a significant joint effect of the two independent variables but with a relatively small R^2 ($R^2 = .10$). (The dependent variable in this regression cannot be expected to satisfy the usual assumptions; the absolute values of the residuals will not be normally distributed and are not statistically independent as noted earlier. Therefore, the regression results and the tests of significance should be viewed with some caution). Since Yhat and O_3 are negatively correlated, it is not clear which of the two factors is responsible for the heterogeneity. However, the contribution of Yhat alone in the model was much larger than the contribution of O_3 alone (10352 vs. 8540, sum of squares). After adjustment for Yhat, O_3 was significant whereas Yhat after adjustment for O_3 was significant. This suggests that the heterogeneity observed was primarily a result of the commonly observed association of mean and variance.

Finally, the Box-Cox estimation of the appropriate power transformation gave an estimate of $\lambda = -0.05$, with the confidence interval on λ ranging from -0.55 to +0.45 (Figure 5.3.5.). The confidence interval clearly overlaps $\lambda = 0$, which indicates the logarithmic transformation. The logarithmic transformation is commonly used when the standard deviation changes proportional to the mean as the nearly linear plot in Figure 5.3.4. suggests to be the case. A log transformation was done on yield and the analyses of variance for the eight data sets were rerun. The residual plots from these analysis showed a random scatter, thus indicating homogeneous variances (Figures 5.3.6. and 5.3.7.). The normal plot on these transformed data also suggested normality (Figure 5.3.8.). These results would suggest that the heterogeneity of variance is primarily due to a variance-mean association and that there is little reason to believe that higher O_3 levels either increase or decrease the risk associated with yield production of the species.

5.3.4. Discussion

The analyses of the residuals from the Raleigh soybean data indicated some heterogeneity of variance even though Bartlett's Chi-square test of heterogeneity of the eight experimental error variances was not significant. The regression analysis and the pattern of residuals suggested that the heterogeneity of dispersion could be explained by an association between the standard deviation and the mean. There appeared to be no need to attribute any of the heterogeneity of variance to the effect of the O_3 level. That is, there is no evidence that higher O_3 levels influence the relative risk associated with soybean production.

The Box-Cox analysis indicated that the behavior of the residuals would be improved with the logarithmic transformation of yield. The analysis of variance and the re-analysis of residuals from the log transformed yield data confirmed this finding.

The amount of heterogeneity observed in the Raleigh data is not great. No single experiment provided sufficient information to clearly demonstrate its presence. In this case, the classical test for heterogeneity of variance, Bartlett's test, over the eight sets of data

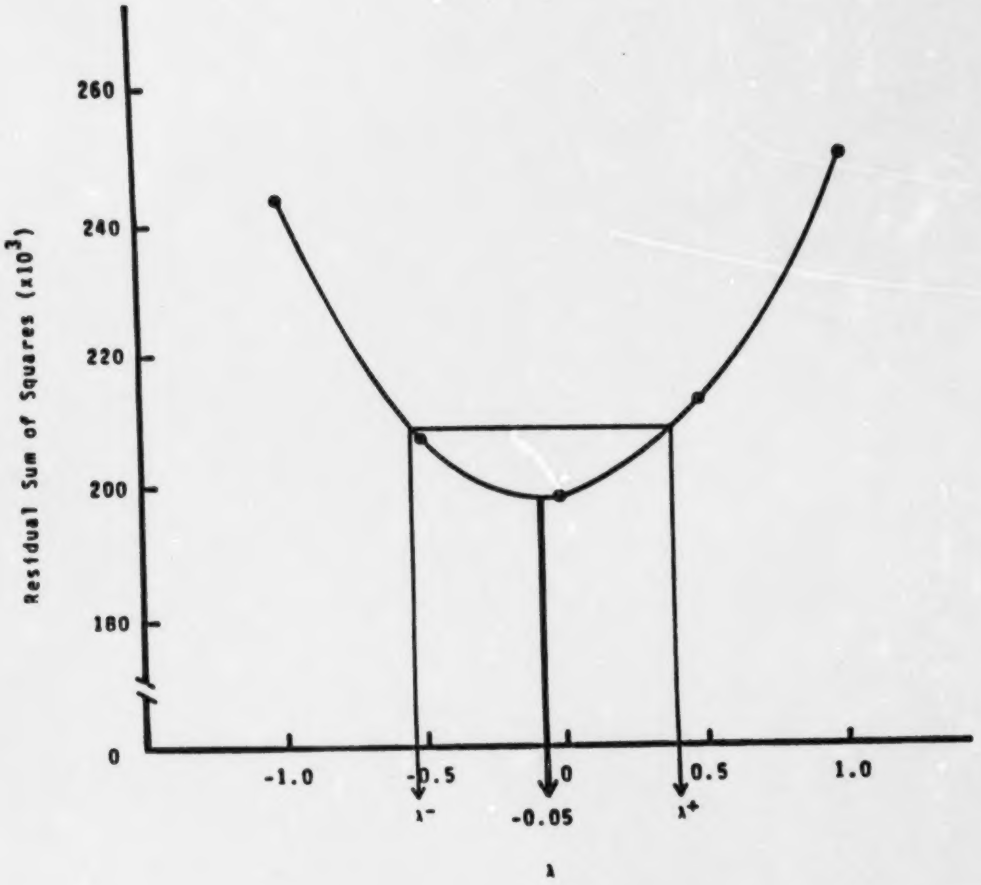

Figure 5.3.5. Residual sum of squares plotted against θ (Box - Cox Power Transformation).

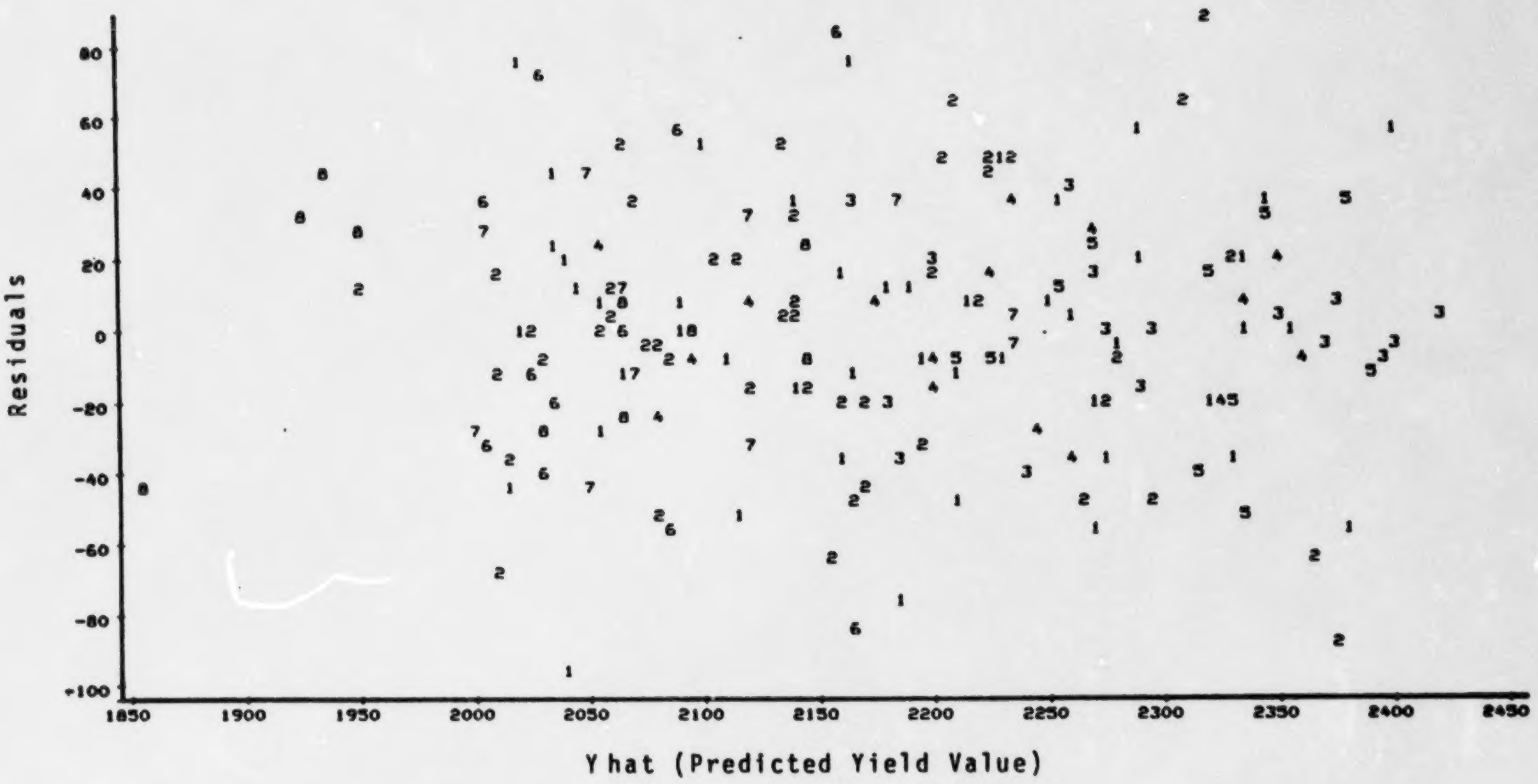

Figure 5.3.6. Residuals versus predicted values from analyses of variance using log transformed dependent variable. The numbers plotted on figure refer to one of eight data sets (see Figure 5.3.2).

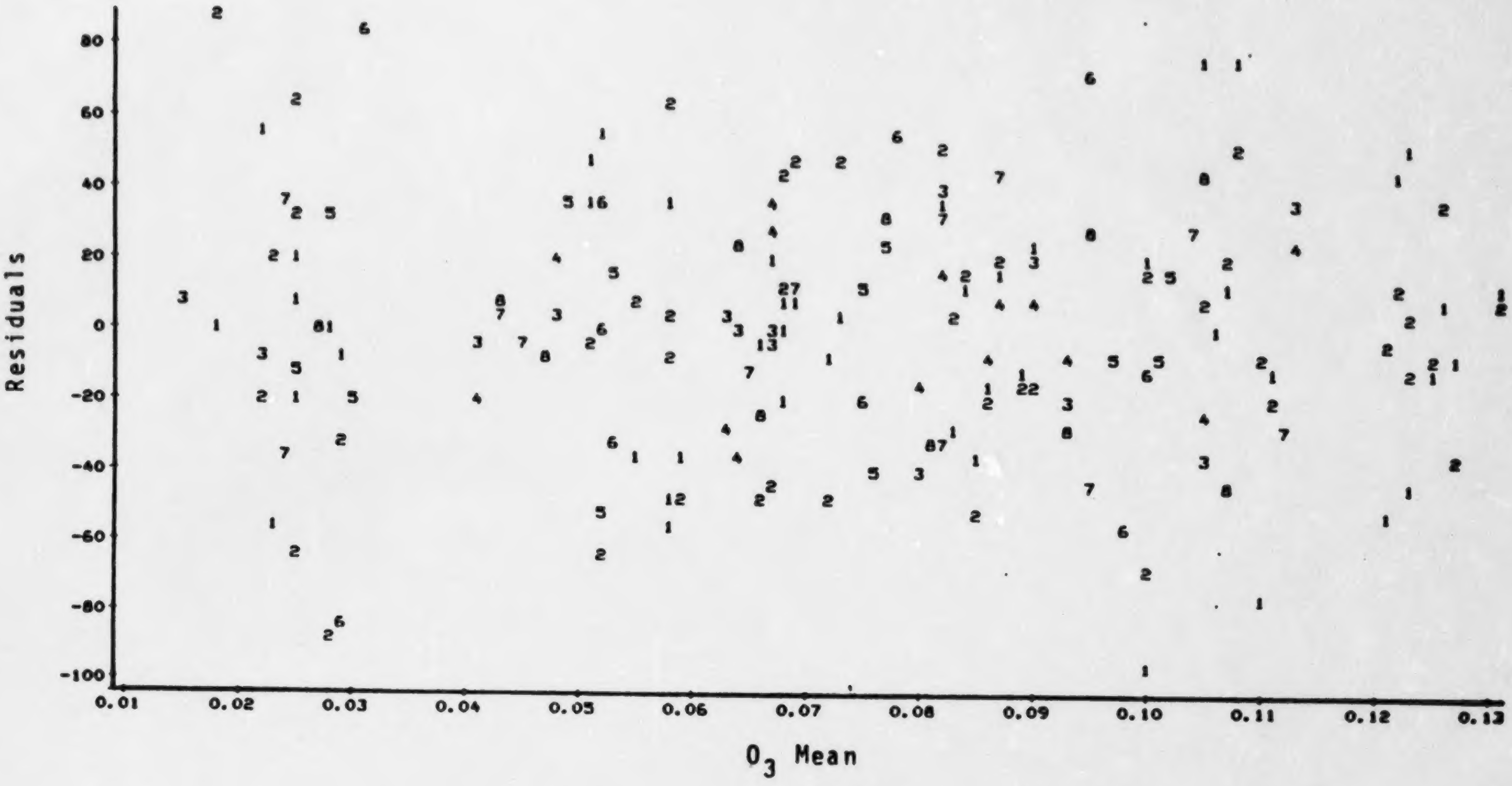

Figure 5.3.7. Residuals from analyses of variance using log transformed dependent variable versus 7-hr O_3 mean. The numbers plotted on figure refer to one of eight data sets (see Figure 5.3.2).

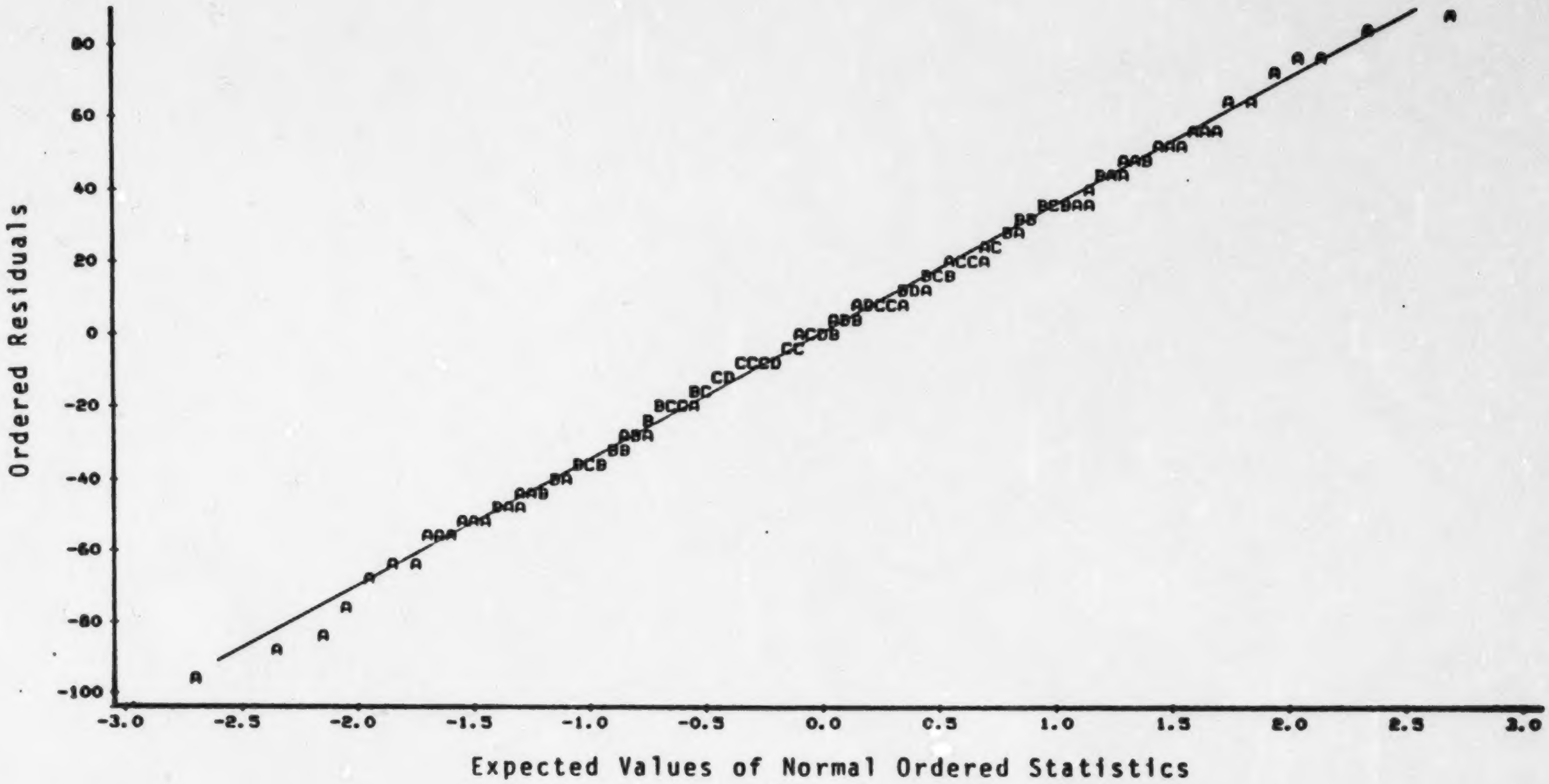

Figure 5.3.8. Normal plot of residuals from analyses of variance using log transformed dependent variable. Letter codes on plot refer to the number of observations at that point on the plot:

A: one observation
B: two observations
C: three observations

still was not significant. It was only the overall pattern of residuals and the Box-Cox transformation that indicated the need for the transformation. This illustrates the additional power that comes from simultaneous analysis of several data sets.

The logarithmic transformation on yield dictates a corresponding change in the dose response model. The Weibull response model is most conveniently expressed in log form if the 'extended α-term' is re-expressed as a product of effects rather than as the sum of effects. With this minor change, the log transformation of the Weibull model makes it linear in the parameters except for one term, a $-(x/\sigma)^c$ term. The parameters of the log-Weibull retain their original interpretation. Preliminary results of fitting the log-Weibull to the Raleigh soybean data have been good.

SECTION 6

USING KRIGING TO ESTIMATE THE MONTHLY MEAN OF THE DAILY MAXIMUM 7- AND 12-HR O_3 CONCENTRATIONS FOR 68 REGIONS IN THE UNITED STATES (NWRCLAP)--A.S. Lefohn and H.P. Knudsen

6.1. Introduction

As a follow up to the original 1982 NCLAN kriging effort (30) and the recent review of NCLAN's use of kriging to predict 7-hr seasonal values (31), ordinary kriging was used to estimate the monthly mean of the daily maximum 7- and 12-hr O_3 concentrations for the years 1980, 1981, 1982, 1983, and 1984 for each of 68 geographic areas in the United States. The estimated values will be incorporated into the NCLAN economic assessment projections that will be constructed by Richard Adams, Department of Agricultural and Resource Economics, Oregon State University.

The means of the monthly maximum 7- and 12-hr O_3 mean concentrations were determined by calculating a daily maximum 7- or 12-hr mean and averaging the daily value over the monthly period. If 75 percent of the hourly mean O_3 concentrations were not available, then a daily mean was not calculated. If 75% of the daily mean values were not available, then a monthly mean was not reported.

The "filtering" protocol originally implemented by NCLAN to reduce the bias associated with using city-center O_3 monitoring sites was used in our analysis. In its 1982 kriging study, NCLAN investigators were concerned about the selection of stations to be included in the air quality analysis (30). In urban settings, the O_3 concentrations were thought to be lower at city-center than at rural locations because of nitric oxide titration in the city. Therefore, NCLAN investigators hypothesized that by using city-center monitoring stations to predict rural O_3 levels, the resultant estimations might be biased low. Because of this concern, specific monitoring stations located in large metropolitan areas were not included in the 1982 NCLAN analysis.

To assess whether monthly variograms developed for each geographic region provided acceptable monthly O_3 predictions, a preliminary test using monthly 7-hr maximum data for several months was performed. Specific criteria for identifying whether the behavior of the monthly variograms would provide reasonable monthly values were developed.

After completion of the preliminary tests, monthly 7- and 12-hr kriged outputs were developed for the following time periods:

- April-October for each year for 66 geographic regions;
- January-December for each of the years for the Imperial Valley of California and the State of Arizona geographic regions.

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6.2. Verification of the Use of Kriging to Estimate Monthly O_3 Concentrations

To establish whether monthly maximum 7- and 12-hr mean O_3 concentrations could adequately be kriged, several criteria had to be met. The geostatistical technique of kriging was developed to make estimates of spatially correlated data that display an approximately constant variance across the region being studied. Furthermore, the most commonly used form of kriging, known as ordinary kriging, requires that the spatial variable exhibit little or no drift (or trend). If drift is present, then a more sophisticated estimator known as universal kriging should be used.

Ozone is a spatially distributed variable, but one of the key criteria in assessing the merit of kriging to estimate O_3 concentrations is whether O_3 displays spatial correlation. If the monthly O_3 values are correlated, a second criterion to test for is whether the distribution of O_3 values has an approximately constant variance across the geographic region of interest. The final criterion to determine is whether drift is absent.

The criteria were evaluated by performing a statistical study of several month's data for the years 1980, 1983, and 1984. The study included the following steps:

1. Histograms and maps of the data were plotted;
2. Several partitions of the data were partitioned into regions of approximately constant variance;
3. Variograms were calculated for each of the regions;
4. Steps 1 through 3 were repeated several times until homogeneous regions were identified.

The results obtained from each year's analysis were similar. Thus, only results from two months in 1984 are discussed in detail.

Monthly O_3 values at a monitoring site vary from month to month; readings usually are highest in the summer and lowest in the winter. The variability of O_3 values across monitoring sites is also highest in the summer and lowest in the winter. These general trends are shown Figure 6.2.1.

The mean and variance of O_3 values vary across the United States; the West Coast has significantly higher variance than the rest of the United States. For example, using data for July 1984, the variance of O_3 over the entire United States was 171 ppb^2 (Table 6.2.1). When the data were partitioned into West Coast and a region consisting of data from all other parts of the United States, the variance was 359 ppb^2 for the West Coast data and 125 ppb^2 for the data covering others parts of the United States. Corresponding numbers for April 1984 showed a variance of 65 ppb^2 for data encompassing the entire U.S., versus 102 ppb^2 for the West Coast and

Table 6.2.1. Summary of O_3 statistics for April and July 1984.

April 1984

Entire U.S.	West Coast	East of 114 degrees
mean = 44 ppb Variance= 65 ppb^2	mean = 43 ppb variance = 102 ppb^2	mean = 44 ppb variance = 57 ppb^2

July 1984

Entire U.S.	West Coast	East of 114 degrees
mean = 54 ppb variance= 171 ppb^2	mean = 55 ppb variance= 359 ppb^2	mean = 54 ppb variance= 125 ppb^2

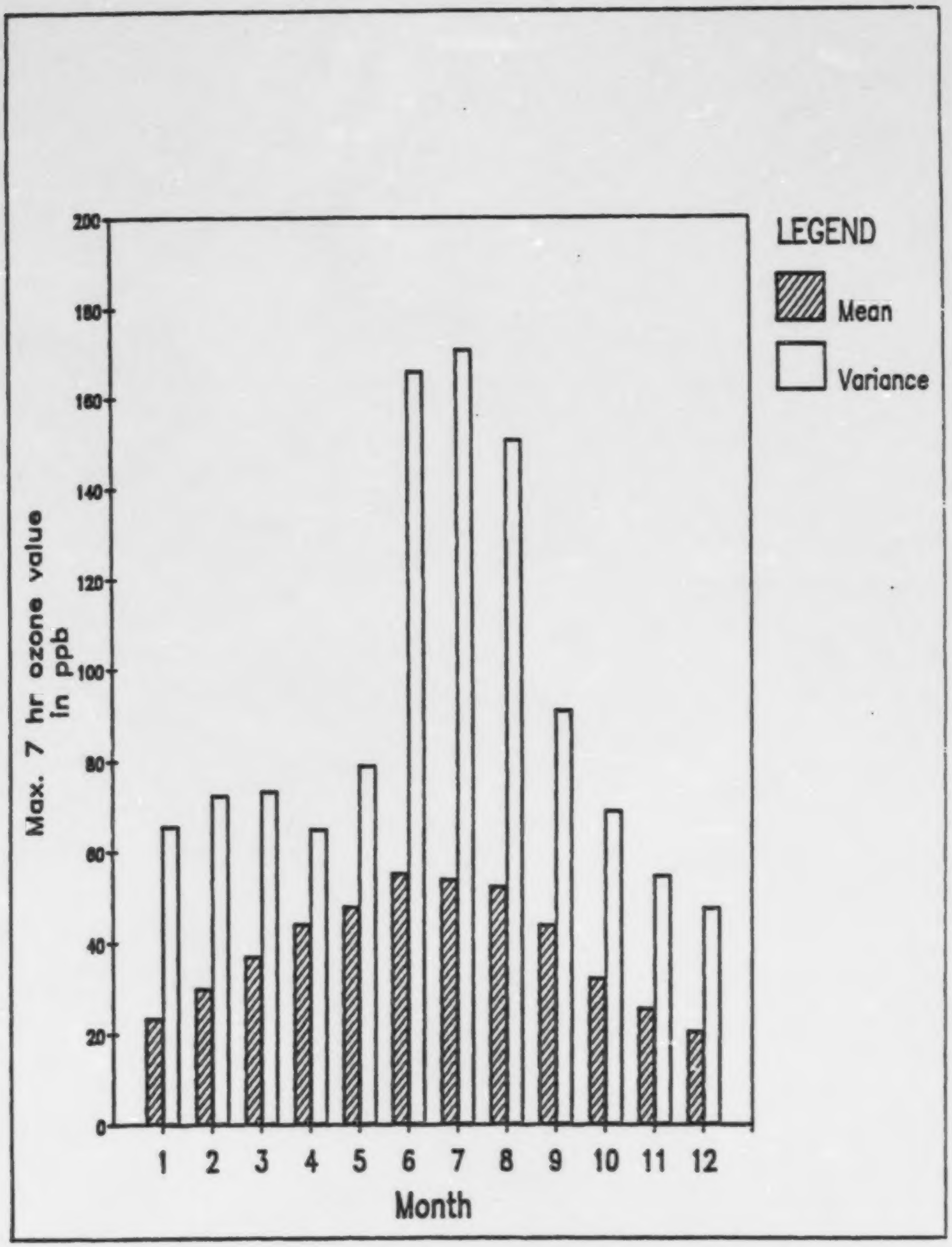

Figure 6.2.1. 1984 maximum 7-hr O_3 values for the United States by month.

57 ppb^2 for the data covering other parts of the United States. After reviewing the data, we decided to partition the U.S. into only two regions; the West Coast (defined as the area West of 114 degrees) and the Eastern U.S. (defined as the area East of 114 degrees). The dividing line was approximately the border between Arizona and California. This line was selected because it separated California, Oregon, and Washington sites from the remainder of the United States.

Several variograms, shown in Figures 6.2.2., 6.2.3., and 6.2.4., illustrate average continuity and demonstrate that O_3 is a spatially correlated variable. The limit of spatial correlation is about 300 km on the West Coast and up to 2000 km for the remainder of the United States. In the summer, O_3 variograms become strongly anisotropic, with the greatest correlation distances in an E-W direction and least correlation in the N-S direction, an effect observed in Figure 6.2.5. for July 1984.

The variograms shown all have the same general characteristics, except that the overall variance is much lower in the spring and fall than in the summer. The nugget effect (i.e., very short-scale variation) was similar in both April and July 1984, possibly because of a constant variance of measurement error at monitoring sites throughout the year.

From the variograms, we conclude that monthly O_3 7-hr means were spatially correlated. In our analysis, we found that the monthly O_3 data collected in the continental United States could be partitioned into at least two regions in order to meet our second criterion. In a review of the various maps showing O_3 values, drift was not generally observable. A review of the variograms computed during the study provides further evidence of the lack of a consistent or general drift. Of the more than 200 variograms computed and modeled during this study, only a few showed any evidence of the upward parabolic growth which indicates drift. Based on the observations above, we conclude that monthly O_3 data can be used to estimate O_3 levels in the United States when sufficient spatial coverage is available.

As specified in the Introduction, monitoring sites classified as 'City- Center' and located within metropolitan areas were deleted. These sites were located in

Boston
Cincinnati
Chicago
Dallas
Denver
New York
Philadelphia
Phoenix
St. Louis
Tampa Bay

In addition, sites located in the South Coast Air Basin of Southern California were removed.

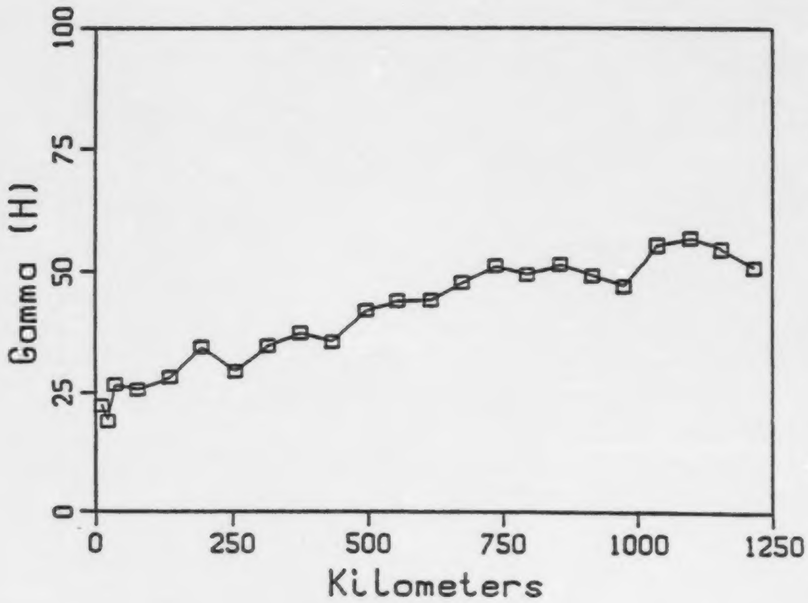

Figure 6.2.2. Variogram of April 1984 maximum 7-hr O_3 values for the Eastern United States.

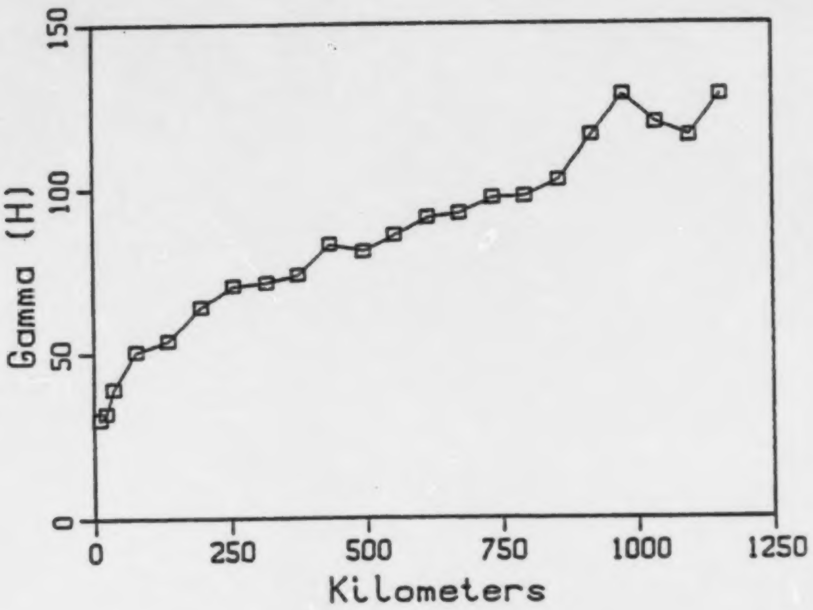

Figure 6.2.3. Variogram of July 1984 maximum 7-hr O_3 values for the Eastern United States.

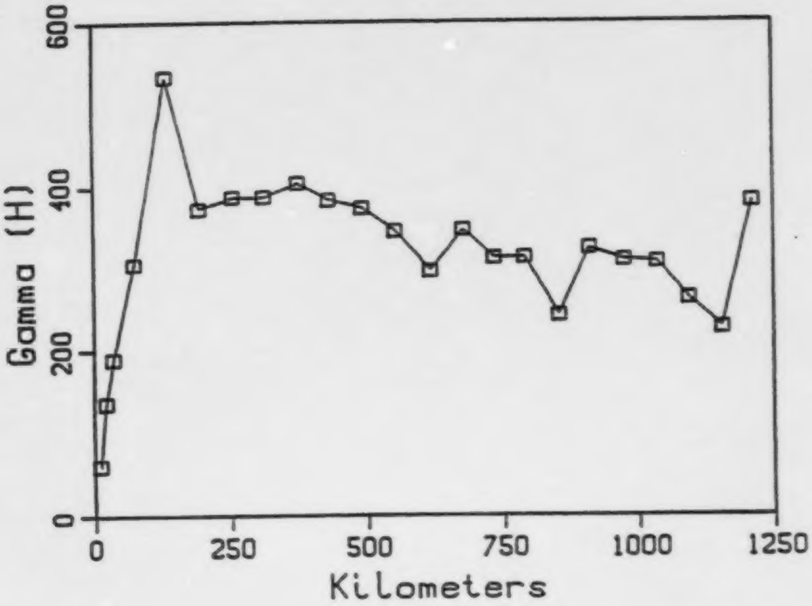

Figure 6.2.4. Variogram of July 1984 maximum 7-hr O_3 values for the West Coast.

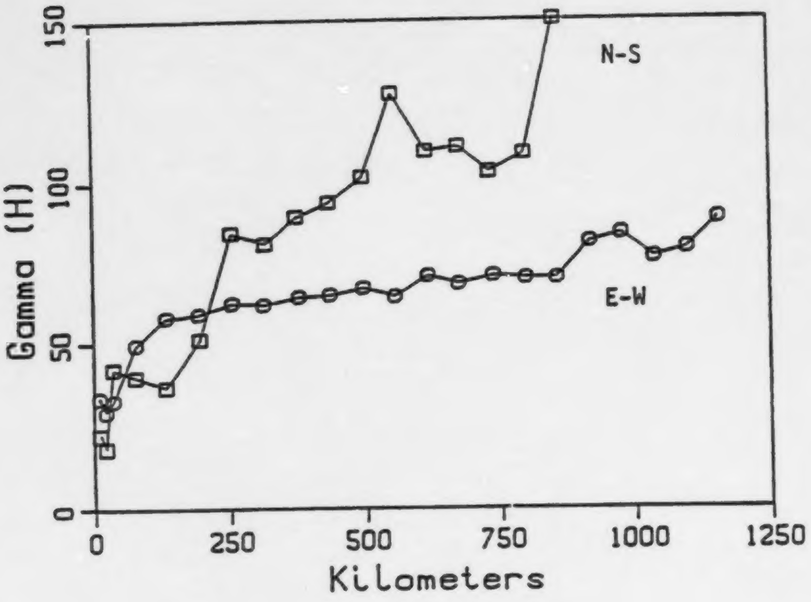

Figure 6.2.5. East-West and North-South directional variogram of July 1984 maximum 7-hr O_3 values for the Eastern United States.

6.3. Data Statistics

Basic statistics, histograms, and boxplots were calculated for each of the 130 different monthly and regional data sets. In this section, certain general aspects of the data are given.

Monthly O_3 values at a monitoring site varied from month to month, but in general, the values were highest in the summer months and lowest during the winter months, a trend prevalent for both the maximum 7-hr and 12-hr values and for all areas of the country. As anticipated, the 12-hr values were always slightly lower than the 7-hr values. The variance of the O_3 values follows the same pattern as the mean (i.e., the summer readings experienced a higher variability than the winter readings).

Year-to-year variations of the O_3 values are shown in the comparison of monthly mean values given in Table 6.3.1. Note that monthly mean values are fairly constant from year to year. For instance, the April readings are in the range of 42.0 to 45.7 ppb O_3, while the July readings were from 53.6 to 63.0 ppb. In the area East of 114 longitude, July had the highest average readings each year except in 1984, when June had the highest average monthly reading.

The variance of the monthly values given in Table 6.3.2. is not nearly as consistent from year to year as the mean values. In 1982, for instance, the variance for each month was much lower than in other years.

The distribution of monthly O_3 values in the East was usually fairly symmetric and displayed a slight negative skewness. No attempts were made to test the goodness-of-fit to a normal distribution. The distribution of O_3 values in the West usually displayed a slight positive skewness.

6.4. Variogram Calculation

The task of calculating variograms for every month for five years for two data types and for two geographic regions required that a fairly set procedure be followed. The 1984 data were extensively studied to determine the best parameters and procedures to be used in the variogram calculations. Particular care was used to determine the presence and likely directions of anisotropy. Although many of the directional variograms were unstable and did not appear optimum, the dominant direction of anisotropy was consistent from year to year and always showed that the E-W variogram had the greatest range of influence and the N-S, the least. Because of sometimes poor variograms, the anisotropy directions could be off by at least 30 degrees (i.e., it may be that in some months, the anisotropy may, in fact, have had its greatest range in the N60E direction rather than E-W). The anisotropy was not as noticeable in the cooler months.

The following kriging calculation and modeling procedures were employed:

1. Three variograms were calculated; an omnidirectional variogram, an E-W variogram, and a N-S variogram.

Table 6.3.1. Monthly mean O_3 values for the area East of 114 longitude. Units are in ppb.

	1980	1981	1982	1983	1984
April	45.0	42.0	45.7	42.7	44.4
May	53.4	49.5	54.4	47.4	47.5
June	55.7	51.0	50.1	57.9	56.7
July	63.0	54.8	54.5	60.4	53.6
August	54.9	51.8	50.0	60.2	53.6
September	44.3	42.6	42.0	49.5	42.4
October	32.7	30.7	34.4	34.1	31.8

Table 6.3.2. Variance of monthly O_3 values for 1980 to 1984 for the area East of 114 longitude. Units are in ppb^2.

	1980	1981	1982	1983	1984
April	99	72	43	53	57
May	106	60	88	63	51
June	121	114	85	167	121
July	195	113	139	177	125
August	168	116	93	182	110
September	112	124	89	87	47
October	105	60	55	63	52

2. If the variograms did not look good or if they were greatly different than variograms from other years, the data were again checked for bad information. If any suspicious data were found, the variograms were rerun.

3. Once acceptable variograms were obtained, a theoretical model was fitted to them. In all cases, the model consisted of a nested spherical model with geometrical anisotropy. The omnidirectional model was fitted first because it was always well behaved in comparison to the directional variograms which were calculated with fewer data points. Next the N-S and E-W variograms were modeled using the same basic model parameters (i.e., the same nugget affect, the same C values) as the omnidirectional variogram. Usually only the ranges of the spherical model had to be determined.

4. If there were any question about the quality of the fit, the model was crossvalidated using the 'leave one out' or jackknife technique (32).

The variograms calculated for the area East of 114 degrees longitude are dominated by the data in the East because few monitoring stations exist in the Rocky Mountain states or in the Plains states. Figure 6.4.1 shows the monitoring stations for the month of July 1984.

In most months, the omnidirectional variograms were well behaved and easily modeled (see Figure 6.4.2.). The variograms for each month were generally consistent from year-to-year. The directional variograms were less well behaved than the omnidirectional variograms and difficult to model. Anisotropy was very noticeable in the summer months and less pronounced in the Spring or Fall. Figure 6.4.3. shows directional variograms for July 1984.

As expected, the variograms for the maximum 12-hr O_3 values were very similar to variograms calculated for the 7-hr values, which helped in modeling the 12-hr variograms. Usually only a slight adjustment downward of the 7-hr variogram model was sufficient to model the 12-hr variogram.

The West Coast was defined as the area to the west of 114 degrees longitude, which cleanly separated the sites located in California, Oregon, and Washington from the rest of the country. While it might have been appropriate to treat Oregon and Washington data separately from California data, there were too few sites in Oregon and Washington to calculate a separate variogram. Nevada also lies to the West of the 114 degree line, but there were only a few monitoring sites in Nevada.

The variograms calculated for the West Coast area show a shorter range of spatial correlation than data from the Eastern portion of the U.S. The West Coast also differed from the East in that anisotropy could not be established from the variograms, possibly because the area is relatively narrow in the E-W direction compared to the N-S direction. In any case, the E-W directional variogram had too few data points to make a case for anisotropy.

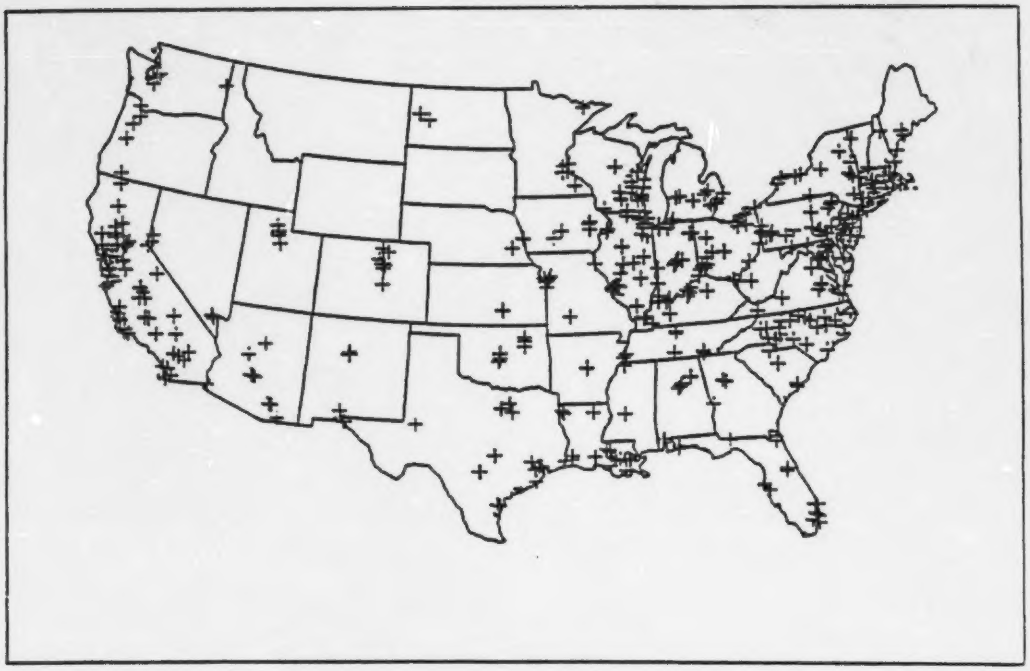

Figure 6.4.1. July 1984 O_3 monitoring sites for the United States.

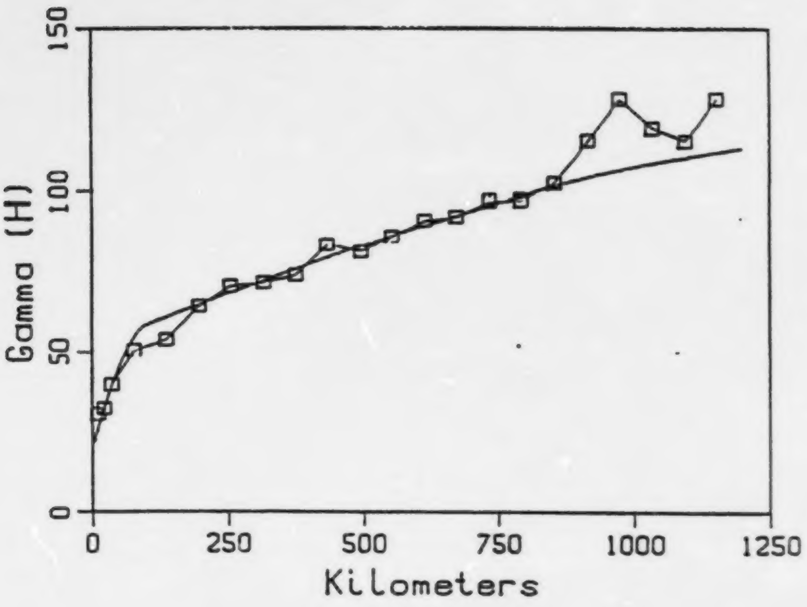

Figure 6.4.2. Omni-directional variogram of July 1984 maximum 7-hr O_3 values for the Eastern United States.

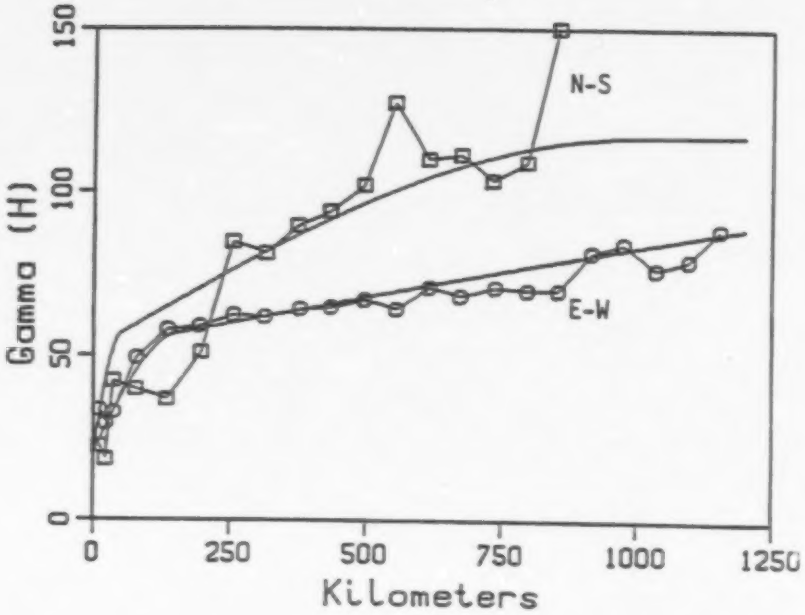

Figure 6.4.3. Directional variogram of July 1984 maximum 7-hr O_3 values for the Eastern United States.

Some of the variogram models were crossvalidated by the 'leave one out' technique (32). In this technique, kriging is used to predict the O_3 concentration at a monitoring site using the surrounding sites but not the site being predicted. The predicted value is then compared to the known O_3 value for that site. This process is repeated for each site. When all sites have been predicted, the statistics of the prediction errors are computed. If the variogram is appropriate, the prediction errors will have a mean of zero and a variance equal to kriging variance which was calculated from the variogram. Table 6.4.1. lists the validation results for the July 1984 variogram. The actual variance of prediction errors, 44.6 ppb^2, is slightly lower than the kriging variance of 48.0 ppb^2 calculated from the variogram. The number of errors within the 95% error bound (2 times the square root of the kriging variance) is 95.6%. Both values indicate the variogram model is good.

6.5. Kriging

The technique of ordinary kriging was used to predict the mean O_3 concentration within each area, not point estimates at the center of the area.

The 68 geographic kriged areas were

1. 41 contiguous states, excluding California, Iowa, Illinois, Ohio, Missouri, and Texas.
2. Subregions within the following states:
    a. California (2)
    b. Iowa (4)
    c. Illinois (4)
    d. Indiana (2)
    e. Ohio (3)
    f. Missouri (4)
    g. Texas (8)

To estimate the mean of a geographic area by kriging, it was necessary to modify a standard kriging program to accept a digitized outline of each of these areas. The digitized outlines of the 41 states were readily available in the DISSPLA graphics package used at Montana College of Mineral Science and Technology. The subregions had to be digitized at Montana Tech. Figure 6.5.1. shows the digitized outlines of the 68 regions as well as the July 1984 mean of the daily maximum 12-hr ± 2 times the standard deviation values.

The main input to a kriging program is the variogram parameters and the search parameters. Since each month has a different variogram, a separate kriging run was necessary for each month, for each zone (different variograms), and for each data type (7-hr or 12-hr). The search parameters used vary with the region being kriged.

Table 6.4.1. Validation of July 1984 7-hr East U.S. variogram. Summary statistics of kriging errors.

Mean	0.17 ppb
Variance	44.6 ppb^2
Std. Deviation	6.68 ppb
Ave. Kriging Variance	48.0 ppb^2
Pct. of Errors Within Two Std. Deviations	95.65
No. of Samples	391

Figure 6.5.1. July 1984 maximum 12-hr O_3 values for the United States.

Throughout the variogram study, the East was defined as the area east of 114 degrees longitude. However, during the actual kriging, the area east of 114 degrees was divided into two zones: the buffer zone and the remainder of the east zone. The buffer zone consisted of Idaho, Utah, and Nevada. The rest of the area was the east zone. Idaho, Utah and Nevada were separated from the other regions because the states border the 114 degree dividing line and are probably correlated or influenced to some extent by the O_3 monitoring sites just to the west of the 114 degree line. Thus, when these three states were kriged, the following search parameters were used:

Maximum search distance = 700 kilometers

Minimum east coordinate of data searched. = 128 degrees longitude

Maximum east coordinate of data searched. = 103 degrees longitude

Maximum number of data used to krig an area = 50 sites

Minimum number of data = 3 sites (within 700 kilometers)

The parameters used to krig the rest of the area to the east of 114 degrees longitude were

Maximum search distance = 1000 kilometers

Minimum east coordinate of data searched. = 114 degrees longitude

Maximum east coordinate of data searched. = 65 degrees longitude

Maximum number of data used to krig an area = 50 sites

Minimum number of data = 3 sites (within 1000 kilometers)

With only a few exceptions, the above search parameters insured that all geographic areas were estimated. In some instances, Montana and Idaho did not have enough monitoring sites within the search distances, so they were not estimated.

The parameters used to krig the rest of the area to the east of 114 degrees longitude were

Maximum search distance = 700 kilometers

Minimum east coordinate of data searched. = 128 degrees longitude

Maximum east coordinate = 103 degrees longitude
of data searched.

Maximum number of data = 50 sites
used to krig an area

Minimum number of data = 3 sites (within 1000 kilometers)

Figures 6.5.2. and 6.5.3. illustrate the results for April and August 1984. On the maps, the upper number plotted in the center of each region is the kriged estimate of the monthly average 7-hr maximum O_3 concentration. The lower number is two times the square root of the kriging variance. If it is assumed that the kriging errors are approximately normally distributed, this number then is a 95% error bound on the kriging estimate.

The kriged air quality information was provided on an IBM PC readable diskette. The air quality information consisted of monthly maximum 7- and 12-hr mean O_3 concentrations by geographic region.

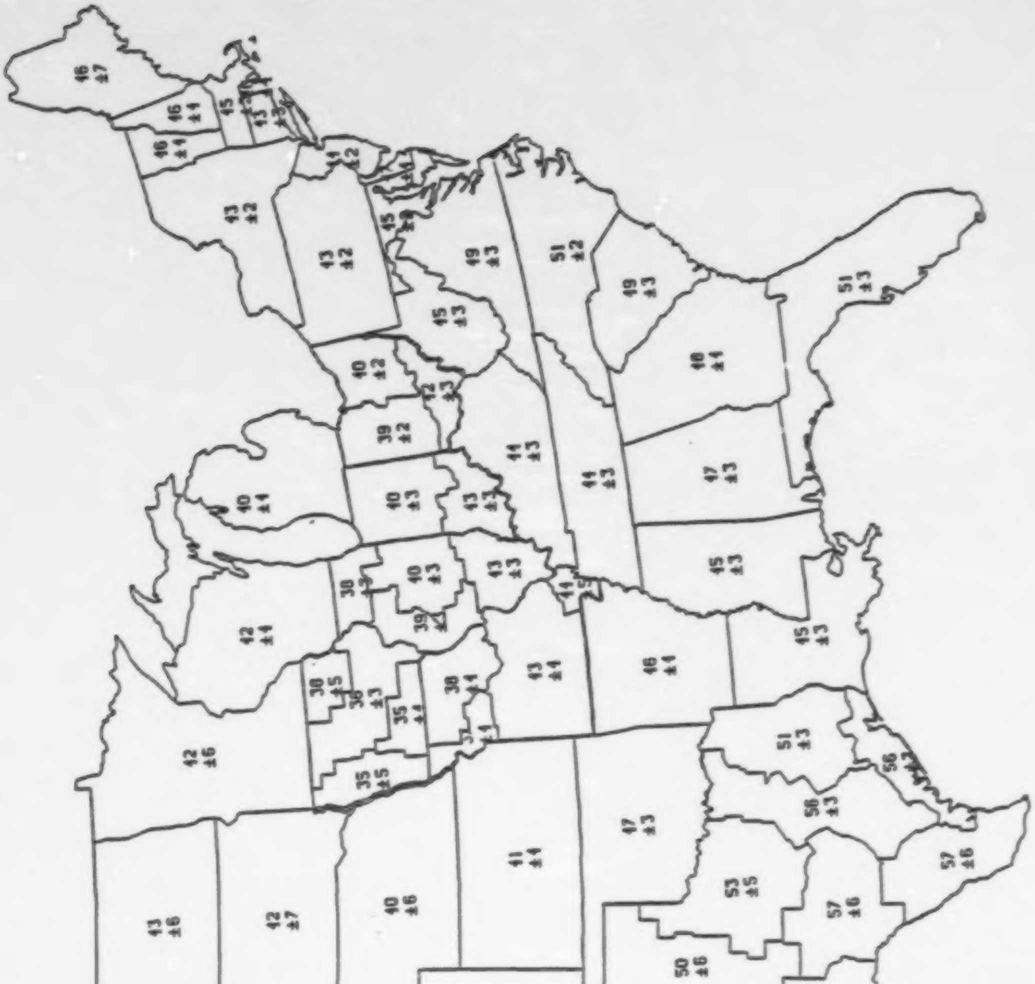

Figure 6.5.2. April 1984 maximum 7-hr O_3 values for the United States.

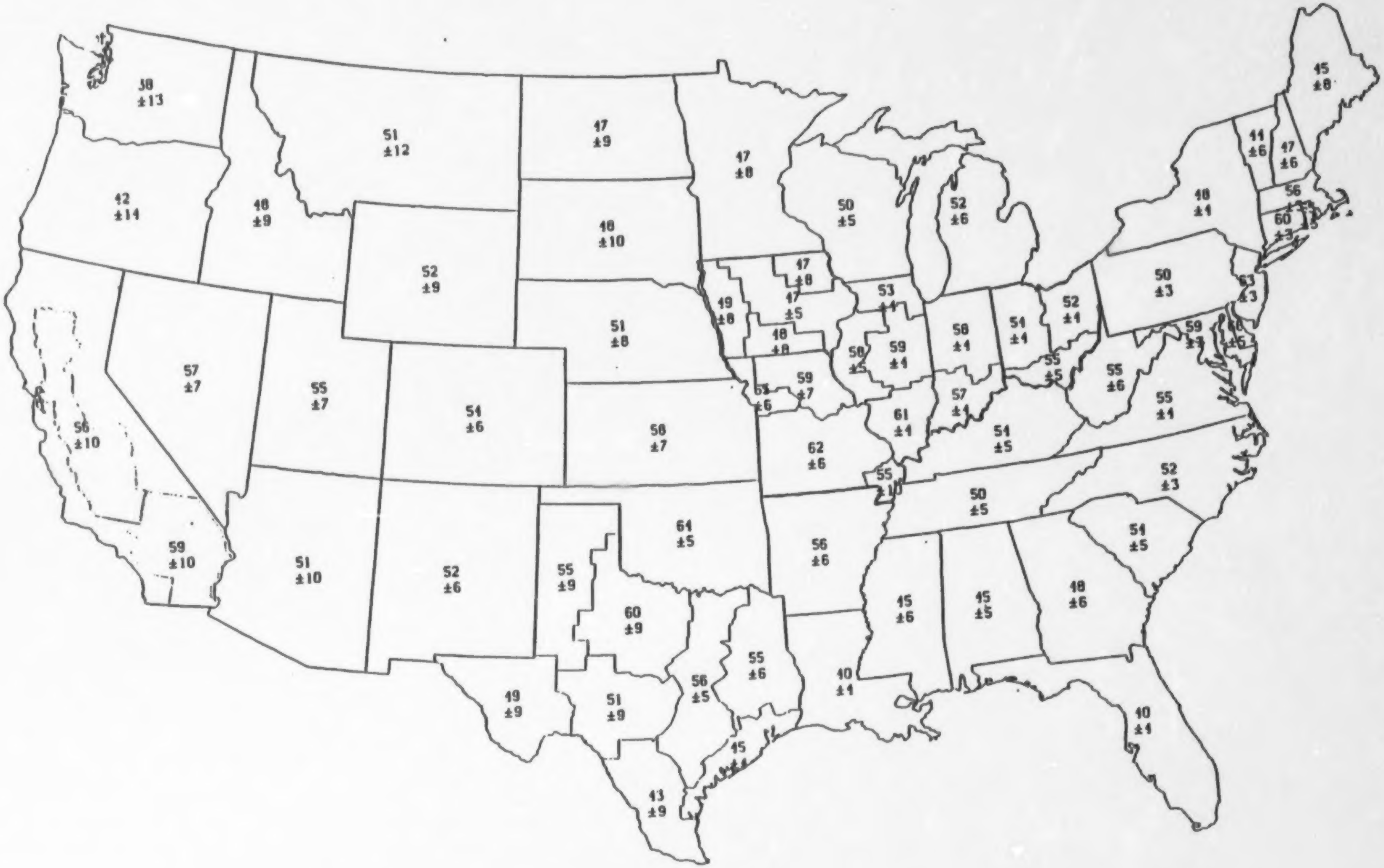
38 ±13
42 ±14
48 ±9
51 ±12
47 ±9
47 ±8
56 ±10
57 ±7
55 ±7
52 ±9
48 ±10
51 ±8
59 ±10
51 ±10
54 ±6
52 ±6
58 ±7
64 ±5
55 ±9
60 ±9
49 ±9
51 ±9
43 ±9
56 ±5
55 ±6
45
50 ±5
52 ±6
47 ±8
49 ±8
47 ±5
48 ±8
53 ±4
58 ±5
59 ±4
59 ±7
63 ±6
58 ±4
57 ±4
61 ±4
62 ±6
55 ±10
56 ±6
40 ±4
45 ±6
45 ±5
48 ±6
40 ±4
50 ±5
54 ±5
54 ±4
52 ±4
55 ±5
55 ±6
55 ±4
52 ±3
54 ±5
50 ±3
59
63 ±3
48 ±4
44 ±6
47 ±6
45 ±8
56
60 ±3

Figure 6.5.3. August 1984 maximum 7-hr O_3 values for the United States.

SECTION 7

AN EVALUATION OF THE O_3 x MOISTURE STRESS MODEL FOR SOYBEAN (NWRCLAP)--D.A. King

7.1. Introduction

A major thrust of the NCLAN program in recent years has been to evaluate the impact of drought on O_3 damage to crops. This effort has involved the following two approaches:

1. Use of moisture stress x O_3 field exposure experiments.
2. Construction of a crop simulation model for prediction of drought x O_3 interactions across geographic regions of interest.

The above simulation model has been applied to soybean, as this crop is likely to suffer the greatest economic losses due to O_3 (4). The model incorporates plant responses to moisture stress and O_3 reported in the literature, but has not been tested against NCLAN experiments conducted to date.

This report presents a test of the model using inputs from the 1984 soybean experiment at Raleigh, NC. Because the object of interest is the potential shift in O_3 effects due to drought, the model was first calibrated to the observed O_3 impact on adequately watered soybean and then run with inputs from the drought-stressed treatments. Comparison of modeled vs observed drought-stressed yields then provides an indication of the adequacy of the model.

7.2. The Model

A detailed description of the model and its rationale is given by King (33). The model is based on the observations that dry matter yield is proportional to seasonal transpiration for a given season, cultivar, and location (34), but that exposure to O_3 may change this proportionality (35). Defining transpiration (TE) as:

$$TE = Y/ST$$

where Y is final biomass per unit area and ST is total seasonal transpiration per unit area, yield can be expressed as:

$$Y = ST \cdot TE \qquad (1)$$

The relative impact of O_3 and moisture stress on yield is then given by:

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$$Y/Y_p = (ST/ST_p)\cdot(TE/TE_p) \tag{2}$$

where Y_p, ST_p and TE_p respectively denote the potential yield, seasonal transpiration, and transpiration efficiency of a crop experiencing no limitation by soil moisture or O_3. The symbols without subscripts refer to the O_3 exposed, drought-stressed crop in question. (Model symbols are defined in Table 7.1.).

Seasonal and potential seasonal transpiration are computed as the respective sums of daily transpiration (T) and daily potential transpiration (T_p), i.e.,

$$ST = \Sigma T \tag{3}$$

$$\text{and } ST_p = \Sigma T_p \tag{4}$$

where the sums are taken from emergence till physiological maturity. Drought may have little effect on transpiration efficiency as defined here, but Reich et al. (35) found that O_3 exposures reduced the transpiration efficiency of pot-grown soybean, as well as reducing transpiration itself. The effect of O_3 on TE is related to its effect on ST as follows:

$$(TE/TE_o) = (ST/ST_o)^{\tau} \tag{5}$$

where TE_o and ST_o are respectively, the transpiration efficiency and seasonal transpiration of a crop experiencing identical moisture stress patterns to the crop in question, but no O_3 impacts. The exponent τ denotes the assumed partitioning of O_3 effects between transpiration efficiency and transpiration.

Daily transpiration, surface evaporation, and soil moisture status are simulated by the model, given daily inputs of pan evaporation, rainfall and irrigation, and hourly O_3 concentrations. The model updates soil moisture status for each day by balancing rainfall inputs against losses due to evapotranspiration and drainage. Daily transpiration is calculated from pan evaporation as modified by crop development status, past drought, and past O_3 exposure as follows:

$$T = E_{pan}\cdot(T_p/E_{pan})\cdot(T_o/T_p)\cdot(T/T_o) \tag{6}$$

where E_{pan} refers to Class A pan evaporation, T_p is the potential transpiration which would occur from an adequately watered crop with no O_3 damage, T_o is the transpiration of an undamaged crop experiencing field moisture conditions, and T is the daily transpiration of a crop

Table 7.1. Definitions of model symbols.

Symbol	Definitions
B	Ratio of SW/PSW below which soil water limits transpiration
D_i	Daily O_3 dose
Dh	Hourly O_3 dose
E_{pan}	Daily class A pan evaporation
F_i	Factor accounting for cumulative effect of O_3 on transpiration
k	Constant indicating chronic effect of O_3 on transpiration
$[O_3]$	Ozone concentration
PSW	Potential available soil water at field capacity
ST	Seasonal crop transpiration
ST_o	Seasonal transpiration for crop grown without O_3
ST_p	Seasonal transpiration of an adequately watered crop not exposed to O_3
SW	Plant available water in the crop rooting zone
T	Daily transpiration
T_o	Daily transpiration for crop exposed to negligible O_3
T_p	Daily potential transpiration
TE	Transpiration efficiency
TE_p	Transpiration efficiency of an adequately watered crop not exposed to O_3
Th	Ozone damage threshold
Y	Dry matter yield
Y_p	Yield of an adequately watered crop not exposed to O_3
β	Constant indicating degree of protection from O_3 damage provided by factors which reduce transpiration
τ	Constant indicating effect of O_3 on TE vs ST

experiencing both field moisture and O_3 conditions. All of the above quantities are expressed as daily values per unit ground area.

The ratio T_p/E_{pan} depends on the phenological stage of the crop and reaches a maximum value of 0.9 in the version of the model described by King (33).

The ratio T_o/T_p is modeled in terms of relative plant available water (SW/PSW) using Hank's (36) approach, as follows:

$$T_o/T_p = 1, \quad \text{when } SW/PSW > B$$
$$\text{and } T_o/T_p = (1/B)\cdot SW/PSW, \quad \text{when } SW/PSW < B \qquad (7)$$

where SW is the plant available water in the wettest soil layer accessed by roots, PSW is potential available water in the same layer (soil water content at field capacity minus soil water content at the permanent wilting point), and B is the value of SW/PSW at which soil water is assumed to begin limiting transpiration. The soil moisture distribution is then calculated from surface evaporation, transpiration and infiltration as described by King (33).

Ozone exposure is assumed to cause a linear decline in relative transpiration (35). This response is modeled by defining the ratio of transpiration for a polluted vs nonpolluted crop on the ith day as

$$T/T_o = 1 - F_i \qquad (8)$$

where the transpiration reduction factor, F_i, is proportional to the cumulative effective O_3 dose, defined below. The model first computes the effective hourly dose, D_h, as

$$D_h = (T/T_p)^{\beta}\,[O_3] - Th, \text{ for } [O_3] > Th/(T/T_p)^{\beta} \qquad (9)$$
$$\text{and } D_h = 0, \text{ for } [O_3] < Th/(T/T_p)^{\beta}$$

where, as before, T is estimated crop transpiration for a given day under field conditions, T_p is the transpiration expected from an adequately watered crop grown without O_3 and the exponent β indicates the degree of protection from O_3 associated with reductions in transpiration due to moisture stress and previous O_3 damage $[O_3]$ is the mean O_3 concentration over the hour in question and Th is a threshold concentration which must be exceeded before damage occurs. This threshold is assumed to increase as soil moisture deficits and cumulative O_3 exposure reduce the ratio T/T_p below 1, as shown in equation 9.

The daily dose D_i is then defined as the sum of the effective hourly dose over daylight hours for the ith day,

$$D_i = \Sigma D_h \qquad (10)$$

and the transpiration reduction factor is given by

$$F_i = F_{i-1} + kD_i \qquad (11)$$

where F_i is the value of the factor on the ith day, F_{i-1} is the value on the previous day, and k is a constant expressing the sensitivity of transpiration to effective O_3 dose. Thus, the modeled decrease in transpiration due to O_3 damage increases as the season progresses, but the rate of accumulation of O_3 effects is reduced during periods of soil moisture deficit. This O_3 impact on transpiration also reduces the severity of soil moisture deficits predicted for a given pattern of rainfall, as modeled here.

7.3. Materials and Methods

7.3.1. The Experiment

The 1984 Raleigh soybean experiment used to test the model is described by Heagle et al. in (21). Pertinent details are summarized in Table 7.2. The following description is based on Heagle et al. in (21) and personal communcations from Richard Flagler and Al Heagle. The soybeans were grown in a 28-cm deep layer of Norfolk sandy loam overlaying approximately 20 cm of Appling sandy loam. Potential plant available soil water (PSW) was only 1.9 cm for the above topsoil and about 2 cm for the lower layer. (PSW is the root zone soil water content at field capacity minus the water content at the permanent wilting point, expressed as water volume per unit surface area.) This second layer was difficult to penetrate mechanically and may have impeded root extension. (Neutron probe estimates of soil moisture indicated only a small decline in soil moisture at 45 cm depth over the growing season.) Hence, the root zone was taken to consist of only the above two layers and PSW was set at 4 cm for the model simulations. This value of PSW is small compared to the values commonly found for midwestern soils where much of the U.S. soybean crop is produced (William Nelson, personal communication).

The two experimental moisture treatments are subsequently termed "wet" and "dry." Both treatments received substantial rainfall until early August, after which rains largely ceased. Wet plots received 2.5 cm of water by drip tubing when tensiometer readings at 22.5-cm depth in either plot of a given O_3 level reached -0.03 MPa. Dry plots received 2.5 cm of water when neutron probe readings at 22.5 cm indicated a soil water potential of -0.5 MPa within a given O_3 level (21). As a result, all dry chambers received five simultaneous irrigations, except for the two high-O_3 chambers which received one less irrigation. Results from one dry

Table 7.2. Description of soybean experiment used to test the model. Information from Heagle et al. in (21); phenological dates provided by Richard Flagler.

Cultivar: Davis

Plant spacing: 19 plants/m of row (after thinning), 0.5-m row spacing

Method of exposure: Constant additions of O_3 to nonfiltered air from 9:00-16:00 EST, plus nonfiltered and carbon-filtered treatments.

Moisture stress: Two treatments, one maintaining adequate soil moisture, the other producing soil moisture deficits after mid-season (early August).

Replicates: Two replicate chambers per O_3 x drought stress treatment.

Event	Date
Planting	June 11, 1984
Emergence	June 16
Begin dispensing O_3	July 7
First flower	August 10
Begin pod fill	Sept. 5
End of flowering	Sept. 15
Physiological maturity	Oct. 17
Last day of O_3 addition	Oct. 18
Final harvest	Nov. 6

charcoal-filtered chamber were discarded by the Raleigh researchers due to poor plant growth; results from the chamber were not used.

7.3.2. Model Calibration

The model was used to compute the relative yield of each chamber based on inputs of hourly O_3 concentrations and daily water for each chamber. Daily pan evaporation values reported by the Weekly Weather and Crop Bulletin for Chapel Hill, NC (40 km NW of the experimental site) were used in the simulations. Only one soil layer was modeled here, reflecting the shallow rooting depth at the Raleigh site. The model response to O_3 was calibrated by adjusting the O_3 sensitivity parameter, k, to minimize the variance between observed and modeled relative yields for the wet chambers. The damage threshold, Th, was raised from the initial value of 0.01 ppm to 0.05 ppm, to improve the model fit to these yields. However, as Th is increased, the calculated O_3 depression of transpiration decreases and modeled water use increases. To avoid this shift in water use, potential transpiration was reduced by 15 percent from that calculated by the original version of the model. Other model parameters were set at the values used by King (33), as listed in Table 7.3. The calibrated model was then used to simulate relative yield for each of the dry chambers. Model results were compared to experimental results by regressing relative yield against mean seasonal 7-hr/day $[O_3]$ for each approach and moisture stress level. Linear regression of yield vs $[O_3]$ was chosen as providing the most straight forward comparison of the overall responses to O_3, although experimental variance may decline with increasing $[O_3]$ (Chapter 5, this report). More complex statistical models may decrease residuals, but the common Weibull model response for soybean published by Heck et al. (5) differs only slightly from a linear response.

7.4. Results and Discussion

Modeled and observed yields for each chamber are plotted as a function of mean seasonal 7-hr/day $[O_3]$ in Figure 7.1. The mean observed yield for the drought-stressed chambers was 20% below that for the wet chambers, while the model predicted a 16% reduction in mean yield due to moisture stress. This difference between modeled and observed dry yields was not statistically significant.

Predicted O_3 impacts can best be evaluated by expressing yield in relative terms, such that mean modeled yield = mean observed yield for each of the two moisture treatments. Linear regressions of relative yield vs mean $[O_3]$ had slopes which were within 3% of each other for the observed vs modeled wet chamber yields (Table 7.4.). This agreement reflects the calibration procedures which minimized the variance between modeled and observed relative yields for the wet chambers. A significant negative correlation between observed relative yield and mean $[O_3]$ occurred for both the wet and the dry treatments (Table 7.4.).

Modeled vs observed relative yields for the dry chambers are shown in Figure 7.2. The regression slope for the modeled dry results was 0.7 of the slope for the modeled wet results, as compared to a slope rate of 1.1 for the experimental results. However, the regression slopes for the

Table 7.3. Parameter values for the calibrated model.

Parameter	Value
B	0.5
k	0.026 ppm
Th	0.05 ppm
β	1.36
τ	0.38

Table 7.4. Regression relationships fit to observed and modeled results for soybean. RY is yield relative to mean yield per moisture stress treatment. S_b is the standard deviation of the regression slope.

Experiment		Experimental Results	r	N	S_b
Raleigh, 1984	wet	$RY = 1.469 - 6.69 [O_3]$	-0.82	12	1.48
" "	dry	$RY = 1.542 - 7.31 [O_3]$	-0.75	11	2.18
Combined[a]	wet	$RY = 1.426 - 5.97 [O_3]$	-0.91	20	0.67
" "	dry	$RY = 1.368 - 5.08 [O_3]$	-0.86	20	0.71
		Model Results			
Raleigh, 1984	wet	$RY = 1.458 - 6.53 [O_3]$	-0.99	12	0.23
" "	dry	$RY = 1.337 - 4.55 [O_3]$	-0.94	11	0.52

[a] The combined experiment refers to results from the four NCLAN O_3 x moisture stress soybean experiments reported by Heagle in Heck et al. (21,27).

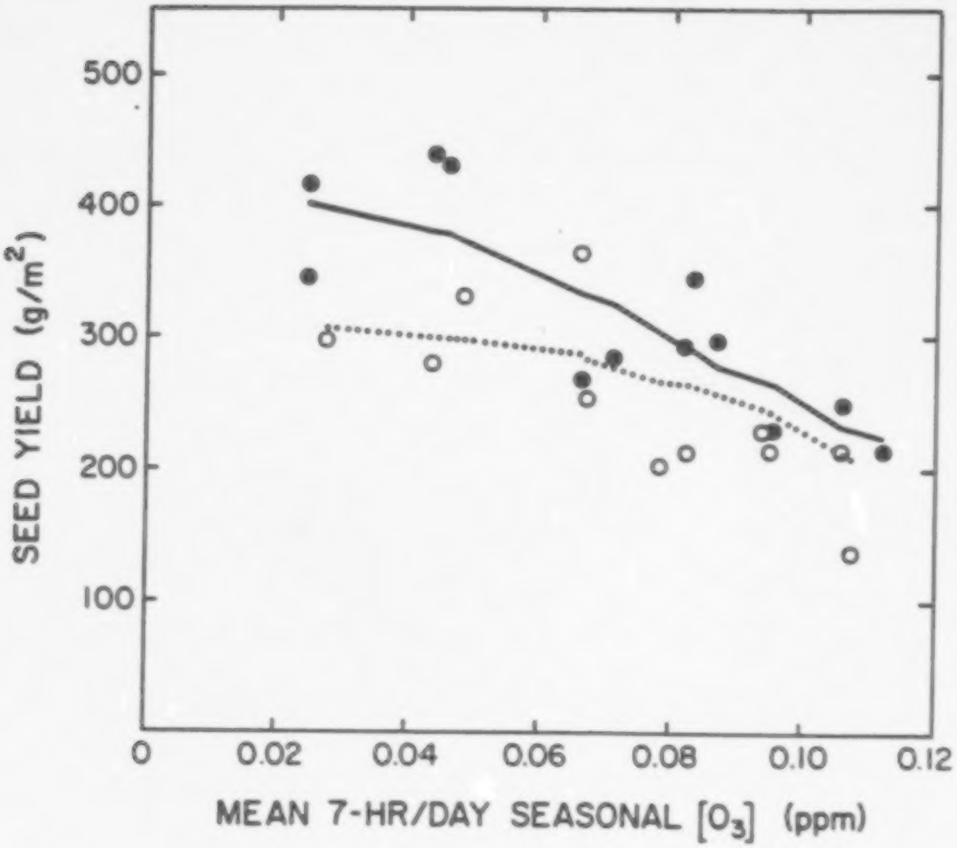

Figure 7.1. Soybean yield per chamber, Raleigh, NC, 1984. Closed and open circles indicate wet and dry treatments, respectively. The solid and dotted lines denote modeled yields for the wet and dry cases, respectively. Seed yield was adjusted to a 13% water content and mean seasonal [O_3] was computed for 9:00-16:00 Eastern Standard Time over the exposure period.

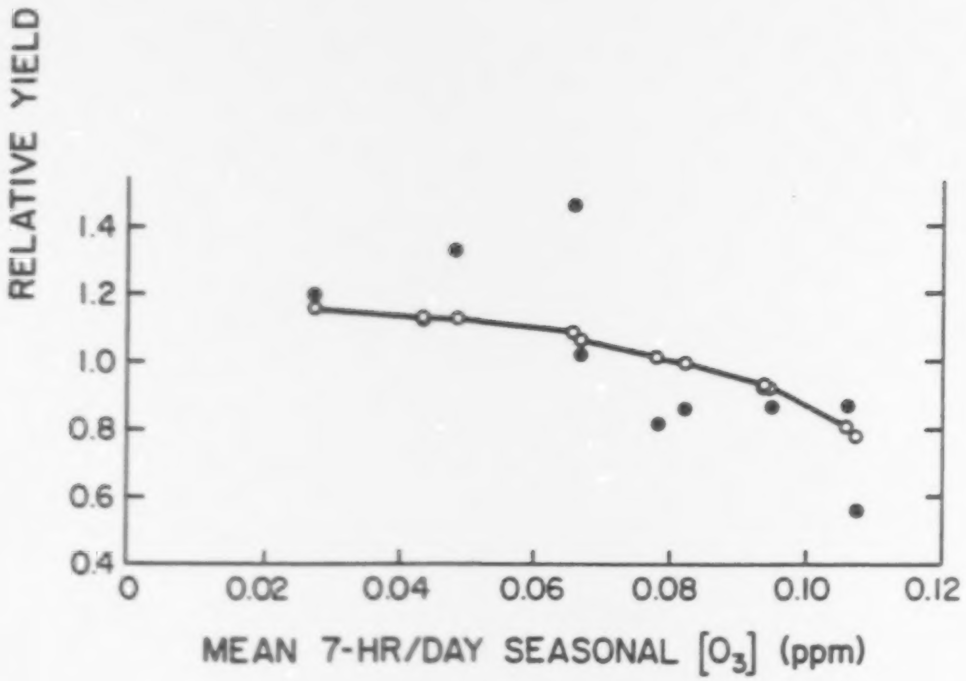

Figure 7.2. Relative per-chamber dry treatment soybean yield, Raleigh, NC, 1984. Closed circles indicate observed yields, open circles connected by lines indicate modeled yields.

modeled vs observed dry results did not differ significantly from each other, due to high experimental variance (Table 7.4.).

The model also predicted some moisture stress impacts on "wet" chamber yields, particularly for the charcoal-filtered treatments where a 5% yield reduction by moisture stress was predicted. This effect is due to the very low value for potential available soil moisture which results in the prediction of drought impacts when soil moisture drops more than 2 cm below field capacity. The magnitude of the above prediction is uncertain due to potential chamber effects on evapotranspiration and uncertainties in pan evaporation, which can vary with site conditions around the pan. Wet chambers were generally watered when tensiometer readings dropped below -0.033 MPa, but these instruments only monitor a single point within each chamber. The possibility that moisture stress impacted the well-watered chambers in this study suggests that water stress effects may have occurred in other "adequately watered" NCLAN experiments, particularly at Raleigh, NC.

In an attempt to determine whether the experimental results described here are typical for soybean, relative yields were calculated for each of the four soybean O_3 x water stress experiments completed by NCLAN through 1984. While it is recognized that the four experiments represent different severities of drought, the combined data set was regressed against $[O_3]$ to provide an indication of the average drought impact on the O_3 response. These relative yields are plotted in Figure 7.3. for both the wet and dry cases. Each point in the figure represents the mean yield for a given O_3 x water stress treatment. The regression of relative dry yield vs $[O_3]$ had a slope of 0.85x that of the regression for the wet treatments but the two slopes did not differ significantly (Table 7.4.). Mean drought impacts on yield ranged from 2 to 50% across the above four experiments, with an average effect of 21% as compared with the 20% mean drought impact observed at Raleigh in 1984. Thus, the overall experimental results suggest a slight, but statistically insignificant, drought impact on the response of soybeans to O_3, while the model predicts a substantial drought x O_3 interaction.

The difficulty in making an accurate test of the model has several sources. First, the impact of moisture stress on the O_3 response is likely to be smaller than the O_3 response itself. Second, the inclusion of two moisture stress levels halves the number of chambers available to define the exposure response at a given water stress level. Third, any differences in soil moisture holding capacity between plots will increase yield variability with drought stress.

The results presented here suggest that drought stress might cause a small decrease in the overall response of soybean to O_3, but that the model may overestimate this reduction in sensitivity to O_3. These conclusions are tentative and do not rule out the possibility that O_3 and drought may interact differentially across a range of O_3 levels, as suggested by Heggestad et al. (7). Three approaches to soybean yield loss assessment are suggested, in view of these results:

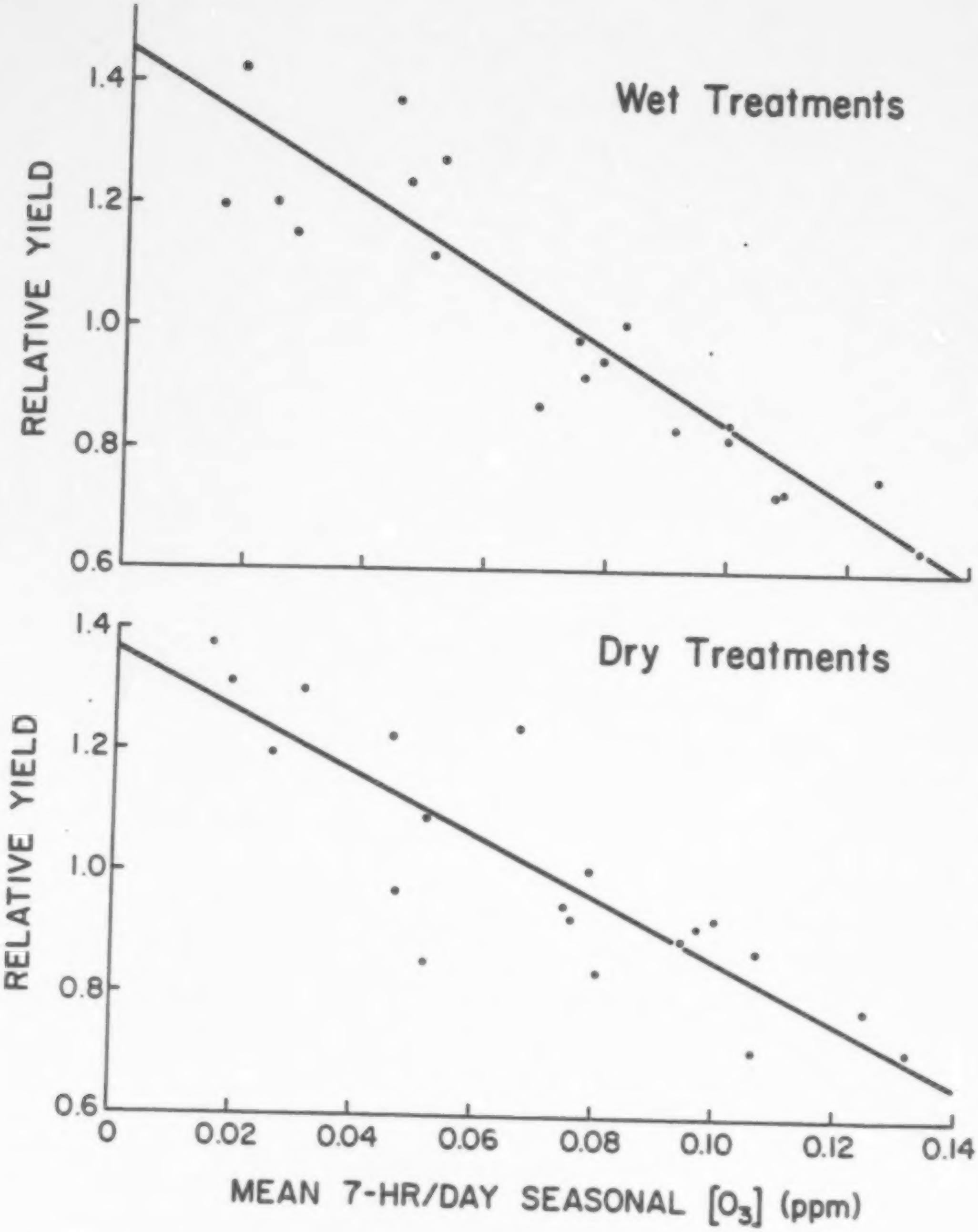

Figure 7.3. Combined relative yields per-O_3-treatment for soybean at Beltsville, MD, 1982 and 1983, and at Raleigh, NC, 1983 and 1984. Relative yield was computed as (yield-per-O_3-treatment)/(mean yield per drought stress level) for each of the four experiments. Lines were fit by linear regression. Relative yields were computed from yields reported by Heagle et al. in Heck et al. (21,27).

1. Use the current model to correct response functions for regional drought stress, as described by King in Heck et al. (21). A benefit of this approach is that it would illustrate how local pollutant-environment interactions may impact regional yield responses to pollutants.

2. Use the experimental results directly to compute an averaged correction factor to the response function for regions where yield is substantially impacted by drought. Drought impacts on regional yield would then be estimated with existing regional crop models (21).

3. Concur that significant moisture stress effects on the O_3 response have not yet been observed for field-grown soybean and make no modification of the exposure-response functions other than to include the drought-stressed results in the computation of the common soybean response used in assessments. This approach to soybean would not preclude using approaches 1 or 2 for cotton where substantial drought x O_3 interactions have been observed (11 and Chapter 4.1.1., this report).

SECTION 8

ASSESSMENT OF THE ECONOMIC CONSEQUENCES OF O_3 ON U.S. AGRICULTURE (NWRCLAP)--R.M. Adams, S.L. Johnson, and W. Moore

8.1. Introduction

The primary objective of the economics component of NCLAN is the assessment of the economic consequences of O_3 on U.S. agriculture. Because of the multi-year timing of the O_3-crop yield experiments used to generate O_3 yield response relationships, this primary objective is to be met sequentially (in two stages). In the first stage, a preliminary assessment of the economic consequences of O_3 on U.S. agriculture is performed using dose response data available from the NCLAN program through the 1983 crop year. NCLAN crop coverage through that year allows an assessment including approximately 75 percent of U.S. crop acreage. The second stage involves the final assessment of the economic consequences of O_3, to be performed in 1987 at the completion of all of the NCLAN crop experiments. The final assessment covers all crops used in the 1984 assessment plus hay and pasture (from the 1985 crop year experiments), increasing the scope of the assessment to approximately 90 percent of total U.S. crop acreage.

The preliminary assessment was completed in 1984. The procedure and results of that assessment were described in detail in the 1984 NCLAN annual report and in several other publications (37,38). In the course of performing the preliminary economic assessment, several economic and biological sources of uncertainty surrounding the economic estimates were identified. Resolution of some of these sources of uncertainty has been a priority of research conducted since the preliminary assessment.

These sources of uncertainty are discussed in detail elsewhere, including the 1984 NCLAN annual report (21) and NCLAN Peer Review Panel reports. Briefly, they include uncertainties arising from 1) incomplete understanding of the ozone-water stress interaction; 2) the effect of exposure statistic or measure on predicted yield response (e.g., 7-hr versus 12-hr seasonal mean); 3) extrapolation from limited site and cultivar responses to large geographical area responses; 4) the effect of O_3 on yield variability, and hence producer risk; and 5) the use of a time- or date-specific economic base model to forecast future economic effects likely to arise from changes in O_3 levels.

For the 1985 project year, the NCLAN economics program was directed towards the last two areas of uncertainties identified above (items 1 through 3 are being addressed in other components of NCLAN). First, an attempt was made to quantify the relationship between yield variability and ambient O_3 levels. Second, the economic model was updated and reformulated to encompass a broader window or period of time. Given that the agricultural environment changes (sometimes dramatically) from year to year, this latter objective is intended to generalize the economic model to provide a better characterization of potential economic effects across

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a range of economic assumptions concerning crop prices, demand elasticities, export levels and other time-dependent parameters.

It is the purpose of this section to discuss progress, procedures and results in 1985 in dealing with these two issues. Section 8.2 discusses the changes and modifications in the economic base model to allow for more accurate estimation of potential O_3 consequences in the 1987 assessment. Section 8.3 presents results from the quantitative investigation of the effects of O_3 on yield variability.

8.2. Updating the Economic Model

Applied economic modeling requires specification and testing of a base period model in order to establish the underlying validity of the model. The economic model used in the preliminary 1984 assessment has as its base year 1980. What this means is that the economic model is calibrated to reflect 1980 values with respect to the economic, agronomic, and environmental variables and parameters used in the construction of the model. The selection of 1980 as the year for the base model in the 1984 assessment was partially determined by the availability of data at the time the model was constructed. (There is typically a 2-3 year lag between a given year and when the data from that year are available from USDA publications and other sources.) The other determinant was the need to select a year relatively free from major disruptions in supply and demand that would result in economic disequilibria. The 1980 year fit this criterion fairly well, in that the period 1978-1980 appears relatively stable in terms of supply, demand and income conditions.

The final economic assessment planned for 1987 requires an updating of the base model (from 1980) to reflect a more recent base period. Updating is a necessity because any attempt to forecast the effects of future policies on an economic sector is more likely to be correct if based upon data and assumptions drawn from a recent time period or years. For example, unlike the period 1978-1980, more recent years have shown chronic oversupply in agriculture due to reduced foreign demand arising from the strong U.S. dollar and increased production in other parts of the world. As a result, the 1987 assessment will be based upon data and assumptions reflecting more recent conditions (through the 1984 year, assuming that all the requisite demand, input, supply parameters are available for 1984 by the fall of 1986).

In addition to updating the model to accurately reflect present conditions, an additional concern in the base model formulation is whether to use a 1-year base or a base model reflecting an average of economic conditions over multiple years. The latter specification has merit in that it is more likely to "smooth out" some of the perturbations and shocks that may hit an economic system in any given year. Since it is difficult to anticipate extreme shocks (because by definition they occur much less frequently than "average" events) and their ultimate effects on a system, the most prudent way to proceed in applied modeling is to use a base period that is relatively uneventful (i.e., the rationale for selection of 1980 in the preliminary assessment) or a moving average of years. This increases the likelihood that estimates from the model present a reasonable picture of that economic sector over time.

As a part of this desire to broaden the window of a 1987 assessment, the economic model is reformulated to give the model the flexibility to reflect any period of years from 1974 through 1984. Specifically, the model data base now contains information on quantities and prices for all model factors and products covering the period 1974-1983. A subroutine has been added to allow the model to be calibrated to any year or set of these years, as required for the analysis. The overall technology base (input-output relationships) is updated to 1983 levels. In addition, export demand conditions have been updated to reflect conditions through 1983. The data required for this updating are taken from recent issues of the USDA Farm Enterprise Data System program (FEDS) and recent issues of USDA, Agricultural Statistics.

With these modifications, the model can now be generalized to a wider array of potential economic and environmental conditions than was possible in the earlier assessment. Hence, the model can key upon values for one year, for a moving average of some set of these years, or a simple average over the entire period, depending upon which time period is most relevant when the assessment is performed. While it is most likely that the assessment will be based on some average of the most recent period (e.g., 1981-1984), should economic conditions change again prior to performance of the assessment, the model's base period analysis can be modified given these new data sets and parameters.

8.3. The Effects of O_3 on Crop Yield Variability: An Exploratory Analysis

The 1984 preliminary assessment measured the direct economic implications of O_3-induced yield changes. In addition to direct effects on expected or average yields, air pollution stress may also lead to change in variability in yields with attendant changes in the variability of producer incomes. An increase in income variability increases the riskiness of production with associated implications for producer welfare. Numerous studies have statistically confirmed the magnitude of the negative yield-O_3 relationship (e.g., 6,10). However, the relationship between O_3-induced crop yield variability and implications for producer behavior have only been discussed qualitatively (16).

The purpose of this section is to quantitatively explore possible links between O_3 stress, crop yields, and the variability of those crop yields. The empirical analysis focuses on the effects of ambient O_3 on selected crops for which recent NCLAN data demonstrate a statistically significant negative relationship between average crop yields and ambient O_3 levels. Two data sets are used to explore the relationship between O_3 levels and crop yield variability. The first data set consists of multiple NCLAN experiments on soybeans and wheat. These experimentally-derived data provide a systematic and detailed basis for investigating this relationship. The second data set consists of farm level data from cash grain farms in Illinois collected by the Illinois Association of Farm Business Farm Management (FBFM). Data from 22 counties over 5 years (1978-1982) are used here. The use of the multi-year, multi-cultivar

NCLAN experimental data coupled with the FBFM Illinois data containing actual producer level yields, input use levels and ambient O_3 levels, provides a comprehensive test as to whether ambient O_3 levels are inducing changes in the underlying variability of yields realized by producers of these crops.

Two procedures are used to analyze the data for variability effects. The first procedure employs a maximum likelihood technique to develop approximations to cumulative distribution functions (CDF) and probability density functions (PDF) for yields of selected NCLAN crops under alternative O_3 levels (39). The estimated probability density functions for each crop and O_3 level generated by this procedure and their specific interquartile ranges suggest how yield variability changes as the O_3 level is altered. This procedure is applied to both single and pooled cultivar NCLAN data.

The second procedure uses a heteroskedasticity adjustment process to measure the effect of input levels in output variability (40,41). Specifically, this procedure measures the effect of input variability on output variability without imposing *a priori* specific signs on the marginal productivity of the inputs themselves. While this procedure can be applied to experimental data, it is best suited to functional relationships containing other covariates (besides O_3) and hence is applied to the FBFM farm level data for Illinois.

The procedures and results are discussed in the following sections. Section 8.3.1. presents a discussion of the probability density functions estimated across the NCLAN data sets using the approximation technique suggested by Taylor (39). Section 8.3.2 describes the Just-Pope (40) heteroskedasticity procedure and estimation results when applied to the FBFM data sets for Illinois. Section 8.3.3 presents conclusions and implications.

8.3.1. An Approximation of O_3-Yield Probability Density Functions

This analysis uses a maximum likelihood procedure (MLE) based on the secant method of Wolfe for solving a system on non-linear equations. Specifically, the program generates estimates of coefficients for the conditional cumulative distribution function (CDF) under that formulation using a hyperbolic tangent transformation procedure (39, p. 1). One of the main advantages of this approximation method is that it avoids any assumptions of normality in the estimation for the CDFs by using a third degree Taylor expansion of the function in two variables (to better approximate the true structure of the CDF). Thus, one can generate skewed and/or bimodal distributions using this method. However, since no functional form is assumed for this CDF, no confidence statements can be made about changes in yield variation over various levels of O_3.

8.3.1.1. Data and procedure

The data used for this analysis are the mean 7-hr O_3 levels and crop yields in kilograms per hectare as reported for each experiment at Argonne National Laboratory. The data are aggregated for different years and for individual cultivars according to scaling schemes. First, data files from the different experiments were grouped together with no adjustments and used in the estimation. If the solution did not converge, a second method was used which adjusts each experiment relative to a base yield level (the average yield for carbon-filtered trials). Thus, the adjusted yields ranged from a little more than 1.0 (for some of the carbon-filtered trials) to about 0.6. If the experiment was jointly testing SO_2 effects on yield, O_3 results from the ambient level chambers (for SO_2) were chosen for the aggregation. Finally, data sets were sorted in ascending order based on yields.

In the estimation phase, a new variable was defined, $Z=.5+.5*\ln[f(Y)/(1-f(Y))]$ for each observation (see: 39, p. 3 for method of calculating f(Y)) which provides starting values for the unconditional probability of yield. Next, OLS is used to regress Y, Y^2, and/or Y^3 against Z to get starting values for the MLE estimation of the unconditional CDF. Next, the variables X, X^2, X^3, XY, X^2Y, and XY^2 were added iteratively with starting values at 0.0, with variables then removed based on low "t" ratios. This process generates alternative specifications of the model, depending on whether the coefficients are or are not zero. The selection of a final model is based on the Schwarz Model selection criterion (42, p. 426). The relevant relationships are defined in equations (1) and (2).

$$F(Y|X) = .5 + .5 \tanh [P(Y,X)] \tag{1}$$

where:

$$P(Y,X) = B_1 + B_2Y + B_3Y^2 + B_4Y^3 + B_5X + B_6X^2 + B_7X^3 + B_8XY + B_9X^2Y + B_{10}XY^2$$

$$f(Y|X) = .5\ P'(Y,X)\ \mathrm{SECH}^2\ [P(Y,X)] \tag{2}$$

Equation (1) defines the CDF and equation (2), its derivative, the conditional probability density function. These functions were plotted for 60 values of Y (yield) and across 5 levels of X (O_3) from the NCLAN data. Using the points calculated for the estimated CDFs, the first, second, and third quartiles were estimated and plotted for each value of X. The change in the interquartile ranges provides a nonparametric method of graphically assessing the effect of O_3 on variation in yield and the skewness, if any, in the distribution.

8.3.1.2. Results

The above algorithm was applied to O_3-yield data on Corsoy and Williams cultivars of soybeans, and an aggregation of Abe and Arthur wheat cultivars. (Regressions on the unadjusted yields for Corsoy and wheat would not converge). The final models are presented below with the standard errors in parenthesis, although they are not directly interpretable due to the nonlinear nature of the function:

Corsoy:

$$P(Y,X) = \underset{(.114)}{-17.03} + \underset{(.142)}{41.19Y} - \underset{(.159)}{42.06Y^2} + \underset{(.166)}{16.70Y^3} + \underset{(1.58)}{33.92X}$$

$$\underset{(16.12)}{-80.73X^2} - \underset{(3.21)}{12.97XY^2}$$

Log-likelihood function = 49.88

Williams:

$$P(Y,X) = \underset{(.128)}{-2.20} + \underset{(.116)}{1.79Y} + \underset{(.176)}{.814XY}$$

Log-likelihood function = 21.68

Wheat:

$$P(Y,X) = \underset{(.116)}{-14.65} + \underset{(.134)}{22.94Y} - \underset{(.138)}{7.57Y^2} - \underset{(1.479)}{51.03X} + \underset{(14.783)}{743.15X^2}$$

Log-likelihood function = 55.66

The plots of interquartile ranges are presented in Figures 8.1, 8.2, 8.3 and show a mixed set of responses. For Corsoy soybeans, the variation in yield as measured by the change in the interquartile range is an increasing function of O_3 levels, implying increasing variability. However, for the wheat cultivars, the opposite situation is observed. Finally, no significant changes in yield variation were detected for Williams' cultivar of soybeans. The associated probability density functions are shown in Figures 8.4, 8.5, 8.6. These findings based on NCLAN data suggest that the null hypothesis (that O_3 does not affect yield variability as manifested in these data) cannot be rejected for wheat and Williams cultivar of soybeans and wheat.

8.3.2. Use of Heteroskedasticity Procedures to Test for Yield Variability

This section discusses an alternative approach to estimate the impacts of O_3 on agricultural yield variability. Specifically, the effect of O_3 on crop output was measured to determine: 1) the correlation between O_3 and yield and; 2) the relationship between O_3 levels and output variability (risk). By using a different procedure and the Illinois data, this second analysis constitutes another test of the variability issues.

8.3.2.1. Procedure

Ozone, like other factors affecting agricultural yields, can be viewed as an input in a production function context. Most production function analyses measure the direct relationship between input levels (e.g., fertilizer) and yield using standard regression approaches. However, some techniques allow estimation of the relationship of input levels to the variability of output. Specifically, the Just and Pope (40)

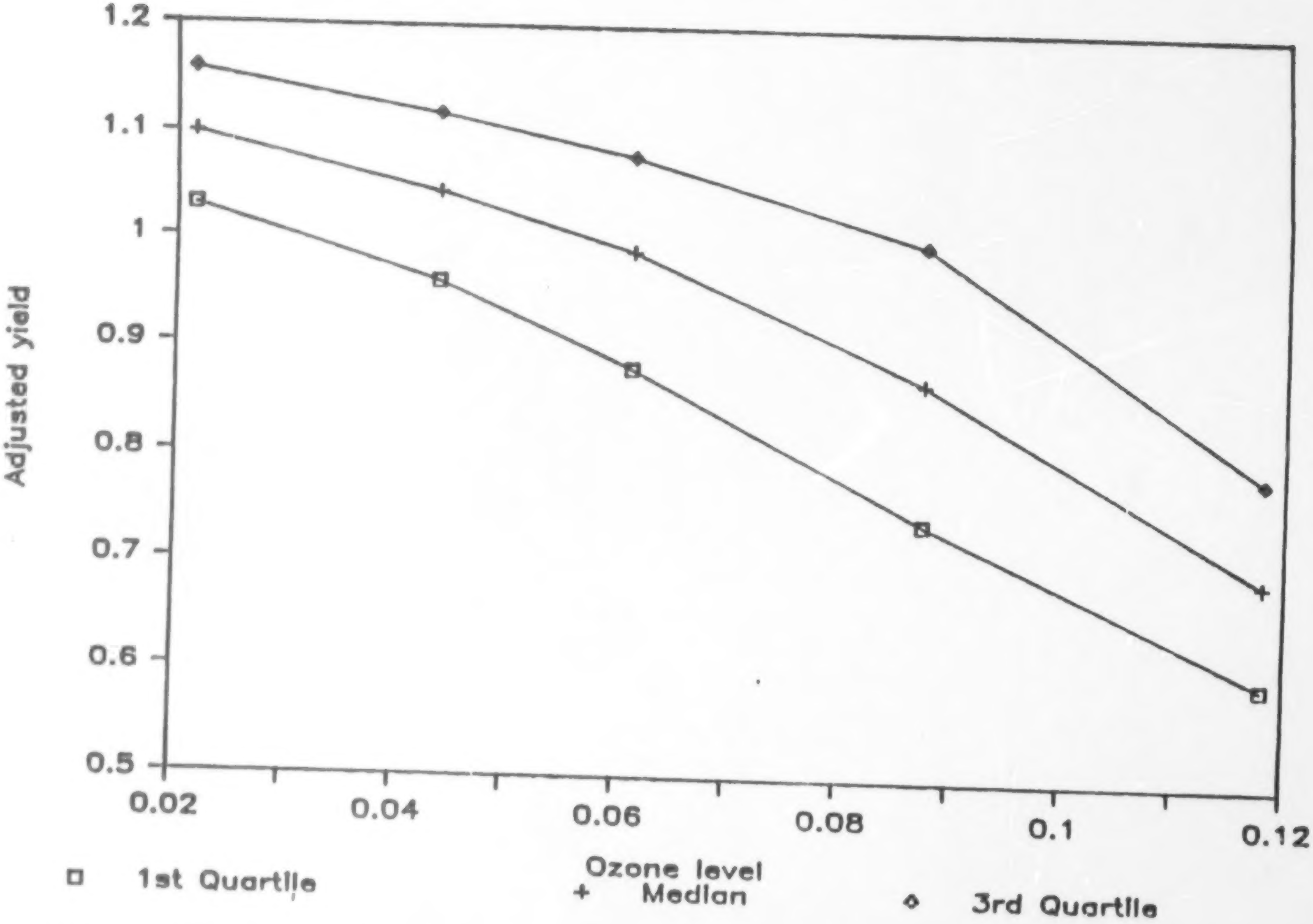

Figure 8.1. Ozone interquartile ranges and the median for adjusted yields of Corsoy soybean CDFs.

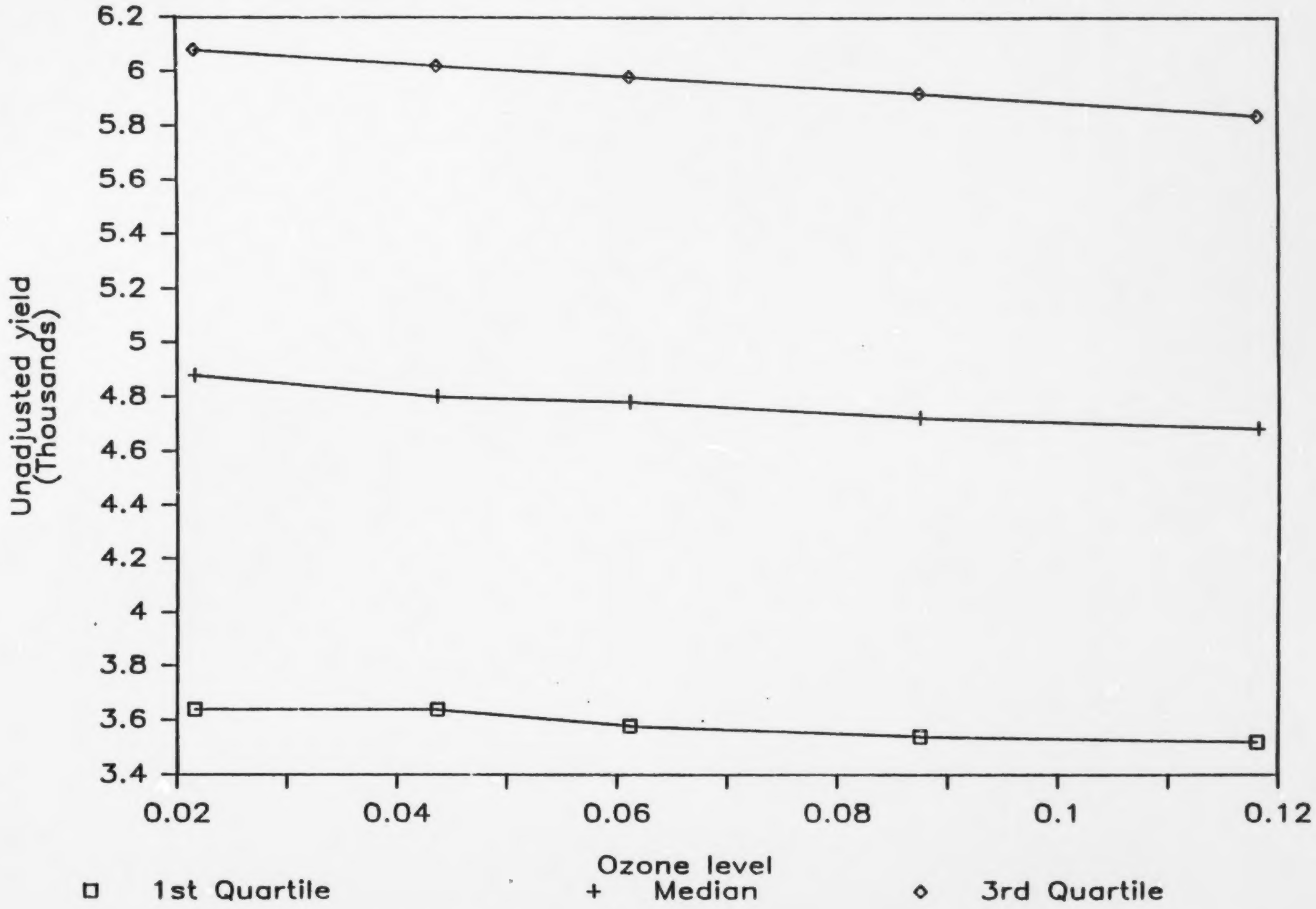

Figure 8.2. Ozone interquartile ranges and the median for unadjusted yields of Williams soybean CDFs.

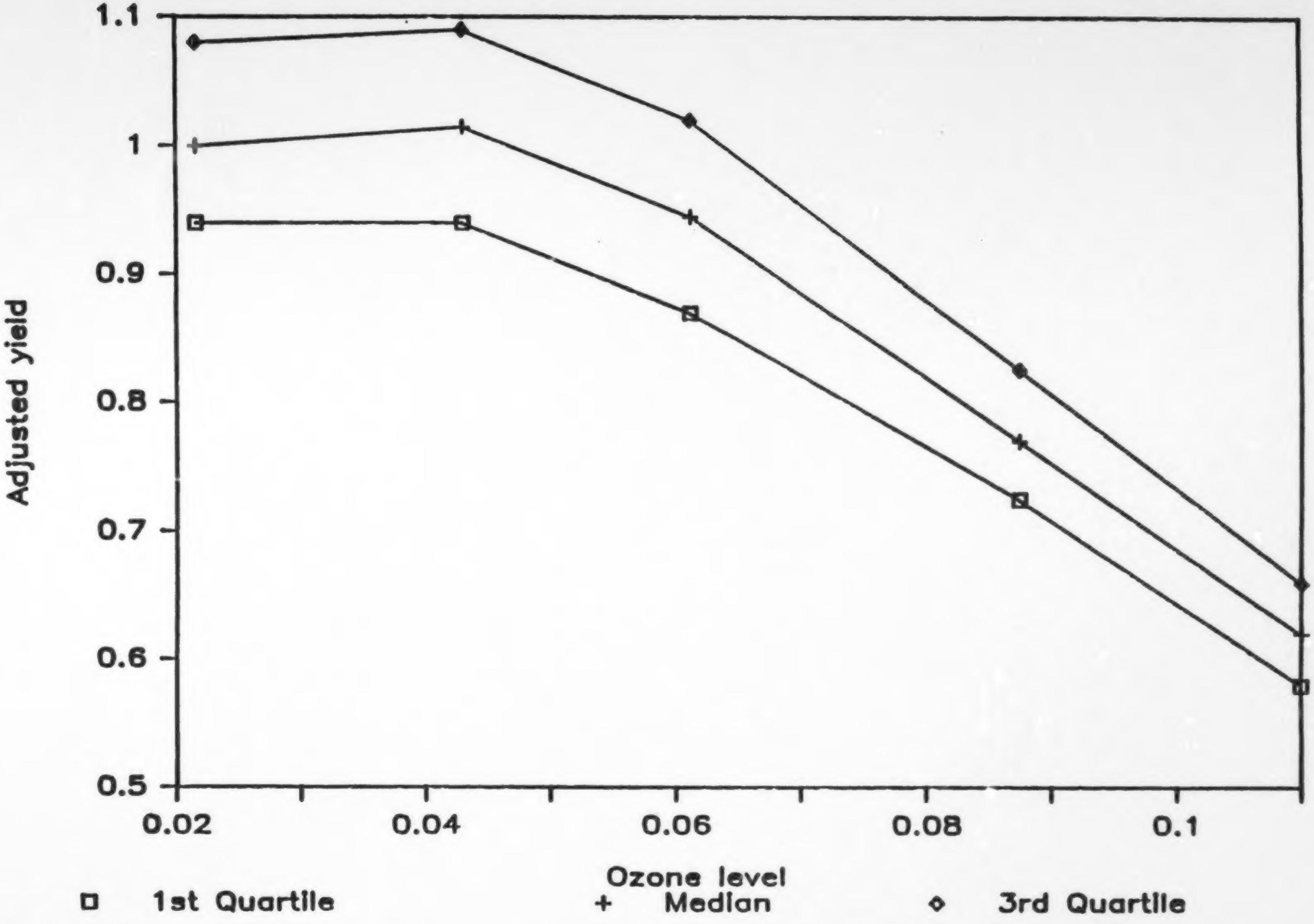

Figure 8.3. Ozone interquartile ranges and the median for adjusted yields of wheat CDFs.

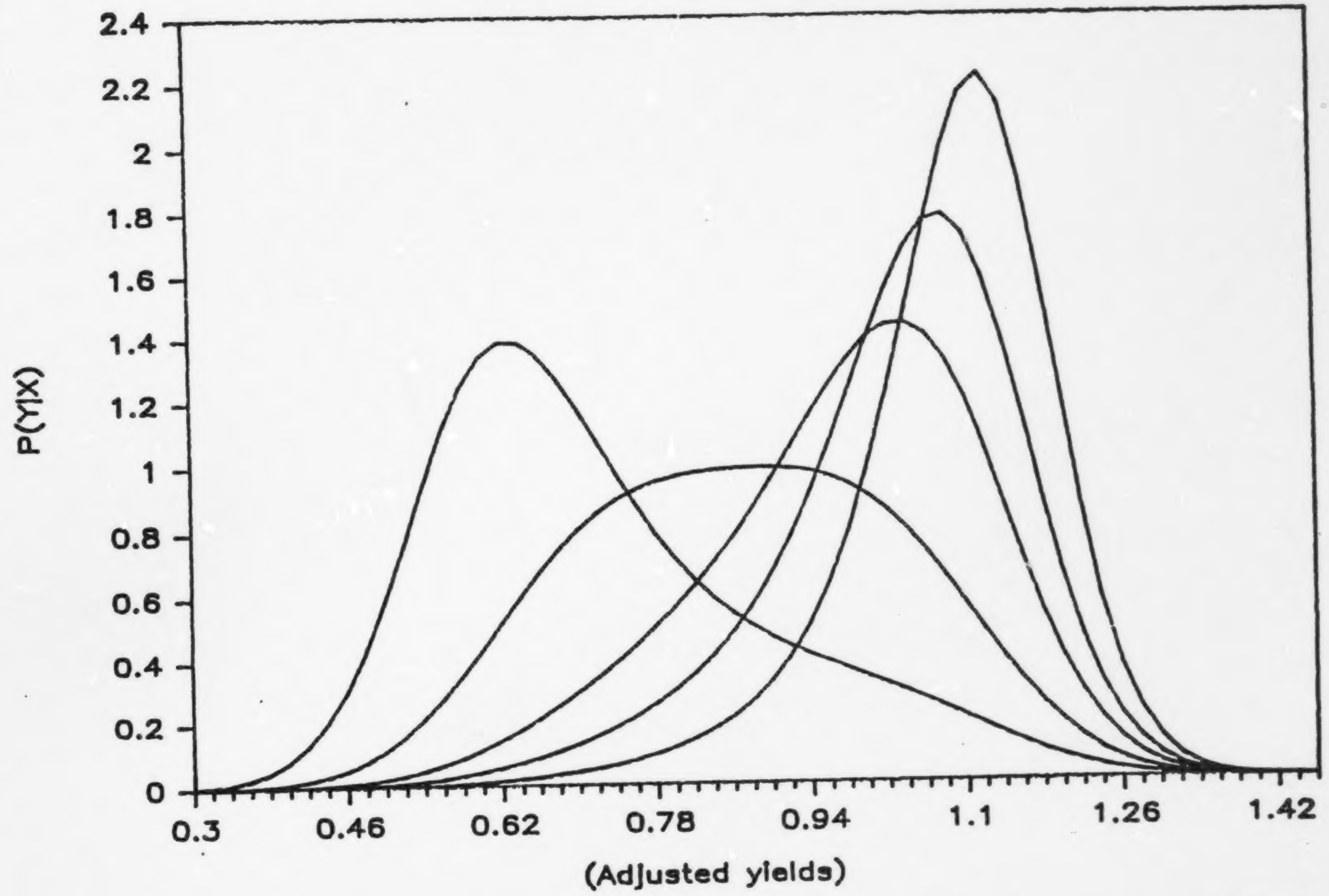

Figure 8.4. Adjusted yields for P (Y|X) for Corsoy soybean CDFs of 0.0216, 0.0437, 0.0612, 0.0875, and 0.1181.

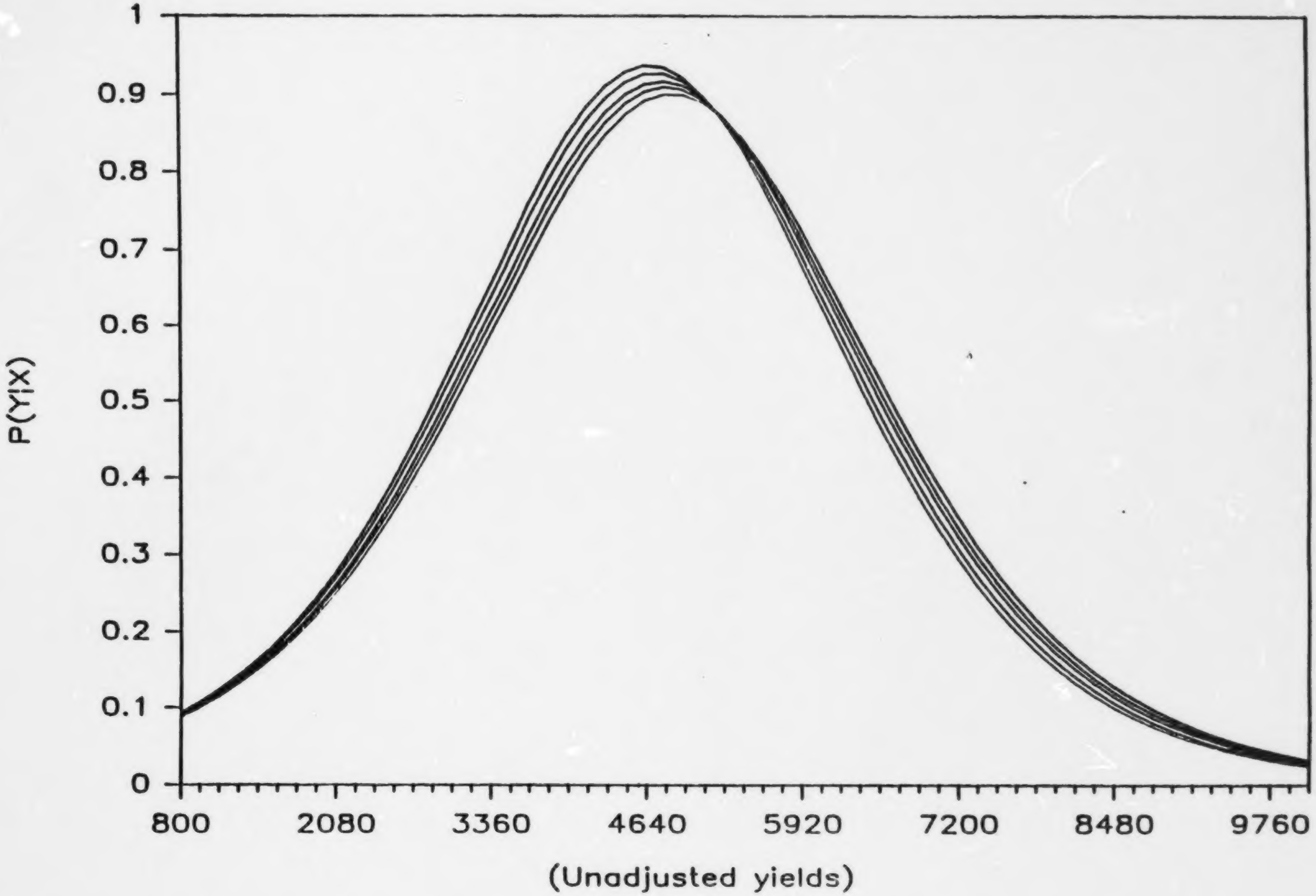

Figure 8.5. Unadjusted yields for P(Y|X) for Williams soybean CDFs of 0.0216, 0.0437, 0.0612, 0.0875, and 0.1181.

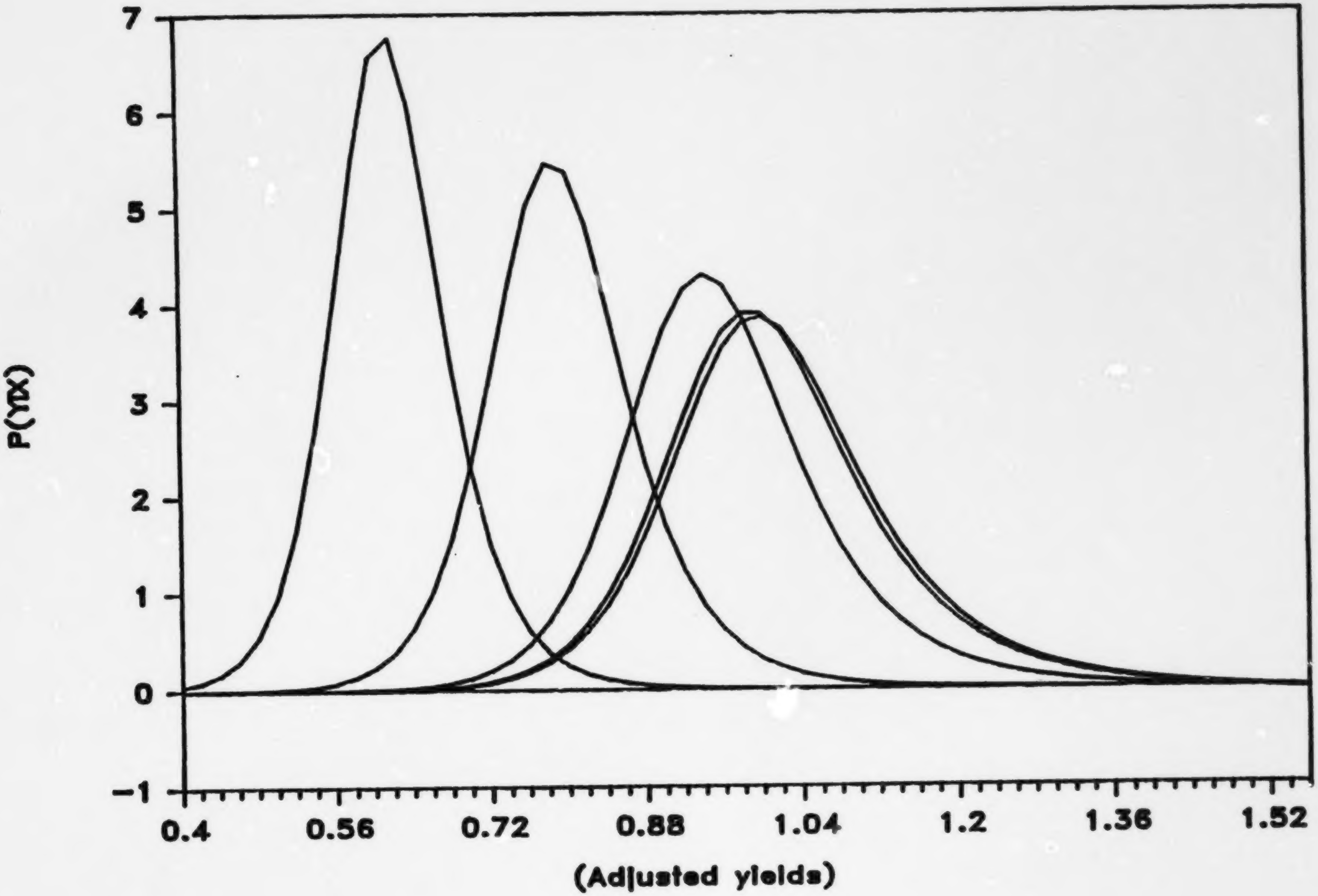

Figure 8.6. Adjusted yields for P(Y|X) for vheat CDFs of 0.023, 0.044, 0.061, 0.088, and 0.118.

technique allows for estimation of both the direct relationship as well as the variability (or risk) implications (reducing, neutral, or increasing) of an input. It does not restrict, a priori, the sign of an input in the risk analysis as traditional production function specifications may do.

Standard production function specifications, such as Cobb-Douglas and translog, generally lead to biased estimates of the risk nature of an input. This is due to the traditional regression formulations which force the effect of an input on output variability to have the same sign as the input's marginal product. Since an input's effect on the mean and variance of output may differ, this specification problem may lead to significant estimation errors.

To eliminate this specification bias, Just and Pope use two functions to separately estimate the effects of an input on output and on the variability of output. These functions can be generalized as:

$$Y = F(X) + h^{1/2}(X)e \qquad (3)$$

where

$$E(Y) = F(X),\ V(Y) = h(X), \text{ and } E(e) = 0 \qquad (4)$$

F(X) represents the correlation between input level and output; h(X) is the correlation between input levels and variation in output. F(X) and h(X) are estimated separately, allowing their signs to be determined independently. Consistent and unbiased estimates of F(X) and h(X) can be obtained using the regression formulations outlined in Stage I and II below.

Stage I of the Just-Pope procedure is an ordinary least squares estimate of F(X).

$$\text{Stage I:}\quad \text{Yield} = a + b_i X_{ij} + c_i X^2_{ij} + e_j \qquad (5)$$

$$i = 1 \text{ to } M \text{ inputs} \qquad j = 1 \text{ to } N \text{ observations}$$

Stage II of the Just-Pope technique estimates the relationship between yield (output) variability and input levels. Yield variability is measured by the residuals (e_j). This equation is estimated using nonlinear least squares.

$$\text{Stage II:}\quad n\ e_j = n(a + b_i X_{ij} + c_i X^2_{ij}) + e_j \qquad (6)$$

It is likely that var (e_{ij}) is not constant given the correlation between magnitudes of inputs and yields. Therefore, the Just-Pope technique allows for correction of possible heteroskedastic disturbances for both simple correlation between inputs and yield (using weighted least squares) in Stage III and estimation of risk relationships (Stage IV). These procedures allow for unbiased, consistent and efficient estimates of F'(X) and h'(X) under the assumption that (5) is the true relationship.

Stage III: $$\frac{\text{Yield}}{Z} = \frac{a}{Z} + \frac{b_{ij}X_i}{Z} + \frac{c_{ij}X_i^2}{Z} + \frac{e_{3j}}{Z}$$

where Z = fitted values of dependent variable from Stage II

Stage IV: $$n\,|e_{3j} \times Z| = n(a + b_{ij}X_i + C_{ij}X^2{}_i) + e_{4j} \qquad (8)$$

The analysis here utilizes a quadratic production function for estimation of F(X), h(X), F'(X), and h'(X). The quadratic form was chosen because it allows for nonconstant production elasticities.

In review, Stage I regression coefficients are estimated by ordinary least squares and indicate the statistical relationship between input levels and output. Stage II regression estimates are obtained through nonlinear least squares and indicate the statistical relationship between input levels and output variability. Stage III regression estimates are corrected for heteroskedastic disturbances using weighted ordinary least squares and should be more efficient estimates than Stage I. Stage IV regression estimates from nonlinear least squares are also corrected for heteroskedasticity. Therefore, Stage IV coefficients provide more efficient estimates of the relationships between input levels and output variability than Stage II estimates.

8.3.2.2. Results

Soybeans. The Just-Pope technique was used to examine relationships between ozone, yields and yield variability using both the experimental NCLAN data and the actual FBFM farm level data for the 22 counties of Illinois over the 1978-1982 period. Since the Just-Pope procedure is intended to estimate multivariate production relationships rather than single variable response functions, the FBFM data are expected to provide a stronger empirical test of this procedure than the NCLAN data. Pooled cross section, time series data comprising individual farm data (for 22 counties) from Illinois were used to examine O_3 effects on soybean yields for the years 1978 through 1982. The 1982 year contained observations from 14 counties. Input use data were available for expenditures (EXP) which was expressed on a per acre basis, soil classification (SOIL), O_3 levels (OZ), July rainfall (RAIN), and average July temperature (TEMP). These variables here included in all regression runs both in first degree and second degree forms. In addition, a variable was added to account for the effects of time on yields (YR) which took on the values 0 to 4 for the years 1978 through 1982, respectively.

Results are presented below for two separate runs, one which utilizes all 102 observations (1978-1982). The other estimation omits the 14 observations for 1982 (N = 88) which is consistent with a previous analysis by Dixon of direct O_3 effects on expected crop yields using these same FBFM data.

Results from Stages I and III were fairly consistent with and without the 1982 observations. Ozone had a negative relationship with soybean yields at a marginally increasing rate. All coefficients were statistically significant at a 95 percent confidence level. The regression coefficients with 1982 observations omitted indicated slightly larger influences of O_3 on yields than did the coefficients with 1982's observations included. Marginal products of O_3 on yields in Stage I were -0.34 without 1982 data and -0.41 with 1982 data. For Stage III estimates without 1982 data the marginal product of O_3 was -0.478. With 1982 data included, the marginal product of O_3 was -0.145. Stage III heteroskedasticity corrections increased explanatory power of both data sets as well as the absolute magnitudes of both factor elasticities and marginal products. The results for each stage are reported in Table 8.1.

A review of the variance-covariance matrices from Stage I and III equations indicate colinearity problems. In particular, the covariance of the TEMP variable with OZ, EXP, SOIL, RAIN, and the respective squared terms, exceeds our variance of these variables more than two-fold. Consequently, it is possible that some or all regression coefficients are influenced by colinearity with TEMP.

Stage II and IV regression estimates for the Illinois farm data as reported in Table 8.2. indicated that O_3 exhibited a decreasing relationship with yield variability at an increasing marginal rate. These findings were consistent both with and without the 1982 observations included in the regression analysis. Heteroskedasticity corrections improved the statistical significance of the O_3 coefficients as well as the overall explanatory power of the equations. The first order term and polynominal term for O_3 were significant at a 95 percent level for Stage IV estimates for the 1978-1981 data set. The Stage IV coefficients for O_3 and O_3 squared, with 1982 included, were significant at a 90 percent confidence level.

The elasticities of residuals and marginal products in Stages II and IV all exhibited compatible signs. With 1982 data omitted, Stage II estimate of ozone's elasticity was -0.0003 and its marginal product was -0.005. With 1982 data included, the elasticity of variability was -0.0045 and its marginal product was -0.17. Stages IV, 1982 omitted, indicated an elasticity of -0.0014 and a marginal product of -0.14. With 1982 included, the Stage IV estimate of elasticity of variability was -0.0033 and with a marginal product of -0.23.

8.3.3. Summary

The effect of O_3 on yield variability is an issue of potential importance in assessing the economic effects of O_3 on the welfare of agriculture. In response to this question, we have quantitatively

Table 8.1. FBFM regression results for Stages I and III, by time period.

Variable	Stage and Time Period			
	I		III	
	1978-1982	1978-1981	1978-1982	1978-1981
EXP	0.2277*	0.2033*	0.3237*	0.1595**
SOIL	1.4551	1.5365	0.0667	- 0.1231
OZ	-19.7020**	-27.2997*	-19.0475*	-24.5569*
RAIN	2.3480	8.3546**	4.5404	11.3791*
TEMP	29.5144	-31.0058	10.2701*	13.5748*
YR	13.6040*	18.9078*	10.7370*	21.8638*
EXP^2	- 0.0007*	- 0.0006*	- 0.0011*	- 0.0004
$SOIL^2$	- 0.0089	- 0.0095	- 0.0003	- 0.0032
OZ^2	0.2403**	0.3265*	0.2336*	0.2916*
$RAIN^2$	- 0.1087	- 0.9104**	- 0.3692	- 1.2107**
$TEMP^2$	- 0.2015	0.2032	- 0.0698*	- 0.0949*
YR^2	- 3.1323*	- 4.1684*	- 2.1489*	- 5.0769*
Constant	-727.30	1682.23	1.21	6.62
R^2	.42	.44	.94	.61

* Significant at 95% confidence level - one-tailed test.

** Significant at 90% confidence level - one-tailed test.

Table 8.2. FBFM regression results for Stages II and IV, by time period.

Variable	Stage and Time Period			
	II		IV	
	1978-1982	1978-1981	1978-1982	1978-1981
EXP	- 0.0375	0.0026	- 0.0674	- 0.0132
SOIL	0.4070	0.2254	0.6788	1.4450*
OZ	- 2.4512	- 1.3099	- 8.2767	-16.0118*
RAIN	- 1.6940	- 0.2385	- 1.5031	1.5346
TEMP	-38.9366	-17.4579	-76.0859**	-114.0266*
YR	1.2506	- 0.1512	3.0940**	2.3709
EXP^2	0.0001	- 0.00001	0.0002	0.00007
SOIL^2	- 0.0026	- 0.0014	- 0.0046	- 0.0089*
OZ^2	0.0278	0.0158	0.0979**	0.1922*
RAIN^2	0.1552	0.2201	0.1553	- 0.2252
TEMP^2	0.2578	0.1170	0.5053*	0.7616*
YR^2	- 0.2196	0.1229	- 0.5405	0.0515
Constant	1514.77	671.59	3017.80*	4535.27*
R^2	.13	.005	.27	.21

* Significant at 95% confidence level - one-tailed test.

** Significant at 90% confidence level - one-tailed test.

explored the relationship between O_3 exposures and changes in yield variability using NCLAN data as well as data generated from surveys of individual farm operations in Illinois. Two procedures were used to sort out possible links between O_3 exposures and yield variability. The results of these procedures were mixed at best.

The first procedure approximates the cumulative probability distribution function for yields under alternative O_3 exposure levels using NCLAN data. The derivative of these CDFs then provided approximations to the probability density functions at each exposure level. An examination of the resultant interquartile ranges suggests that for the Corsoy soybeans an increase in O_3 exposure resulted in an increase in the interquartile range (i.e., the actual variability in O_3 levels in yields increased with increasing O_3 levels). However, for the Williams cultivar of soybeans, the results were inconclusive. Further, for wheat cultivars (Abe and Arthur), an increase in O_3 levels appeared to reduce the O_3 yield variability.

To examine the same potential yield-O_3 phenomenon in a broader context (with other covariates), a second procedure was employed that allows for flexibility in the relationship between input marginal productivity and the effect of that input on output variability. Stage I and III (adjusted for heteroskedasticity) estimates of the coefficients for the individual farm data indicated that O_3 had a negative impact on yields at a marginally increasing rate. Similar estimates based on NCLAN soybean and wheat data of the first and second degree O_3 terms changed signs from Stage I to Stage III. However, the estimated relationships of O_3 on yield variability were inconclusive across the NCLAN and farm level data. Stage II and IV estimates for the farm level data indicated that O_3 had a decreasing effect on yield variability at a marginally increasing rate. Corsoy data indicated that O_3 had a slight negative influence on yield variability.

SECTION 9

INTERNATIONAL CONFERENCE
ON
ASSESSMENT OF CROP LOSS FROM AIR POLLUTANTS

9.1. Scope of Conference

This Conference was recommended and developed by participants in the National Crop Loss Assessment Network (NCLAN) to focus on the current state-of-knowledge and research needs to improve the knowledge base. The Conference is designed to overview the needs for crop loss assessment, current approaches to loss assessment, progress in the development of predictive models, the use of the information for economic predictions, and the use of the data in policy decisions.

The Conference will consist of invited papers that will focus on major themes for each session, contributed short papers on specific research results within general topic areas and contributed posters to complement the presentations in each session. Invited speakers will be asked to focus on current research and research needs in their paper; they should interpret results not just present information. The primary focus will be on research accomplished under field conditions; however, inclusion of greenhouse and controlled environment studies are encouraged where they help interpret or strengthen field studies. Research done in conjunction with model development will be included; these should show how physiological understanding and a knowledge of interactive stresses can improve our assessment and predictive capabilities.

9.2. General Conference Information

Conference Organizers

Walter W. Heck, USDA/ARS, Chairman
O. Clifton Taylor, Univ. of Calif., Co-Chairman
David T. Tingey, EPA, Co-Chairman

Conference Coordinator

Janet McFayden, NCSU

Location

Raleigh, North Carolina

Conference Center

Mission Valley Inn

Date

October 25-29, 1987

Length

Four days with reception on Sunday evening, meetings Monday through Thursday with two sessions each day, Luncheon on Monday noon, Banquet on Wednesday evening

Proposed Registration Fee

$125.00

9.3. General Program

Sunday Night - Reception
Mon. AM - Introductions with keynote speaker (EPA - official) and Opening Session on Crop Loss Assessment
Mon. Noon - Luncheon (Speaker, Congress)
Mon. PM - Session 2: Meteorology/Atmospheric Chemistry/Regional Monitoring - Extrapolation
Tues. AM - Session 3: Field Approaches/Results for Assessing Crop Losses
Tues. PM - Session 4: Physiological Understanding
Wed. AM - Session 5: Interactive Stress Factors - Abiotic and Biotic
Wed. PM - Session 6: Statistical and Simulated Modeling Approaches
Wed. Evening - Banquet (Speaker)
Thurs. AM - Session 7: Economic Considerations and Policy Implication
Thurs. PM - Conference Ends
Posters - These will be up throughout the Conference (Kohut/Kress will coordinate)

9.4. Publishing

There will be two publications coming from this Conference.

1. A hardback (typeset) volume, published by Elsevier, to include all invited papers (21) and brief abstracts of the contributed papers.

2. Publication of contributed papers and summaries of the posters in a single issue of Environmental Pollution - following the Journal's peer review procedures.

9.5. Conference Schedule

April, 1986 - Verbal invitation to session chairmen, co-chairmen, and invited speakers

May, 1986 - Send formal letters of invitation to session chairmen, co-chairmen, and invited speakers

July, 1986 - Send first announcement and call for contributed papers and posters

November, 1986 - Send announcement and final call for papers

March 27, 1987 - Abstracts of presentations are due

April 28, 1987 - Notification of acceptance of contributed papers and posters

Sept. 4, 1987 - Invited and contributed papers due to session chairmen for a general overview

Oct. 2, 1987 - Return to authors with suggestions

Oct. 26-29, 1987 - Present invited and contributed papers at Conference, authors submit final papers to Session chairmen

- Session chairmen will coordinate peer reviews (3) for both the invited and contributed papers following quidelines of the publishers and conference committee

Dec. 11, 1987 - Return papers to authors with final comments and peer review comments

Jan. 8, 1988 - Authors submit final papers to Conference Organizers; papers will be edited for consistency by Conference editors

Feb. 17, 1988 - Return papers to authors for final concurrence

March 1, 1988 - Papers returned to Conference Organizers for final review

March 17, 1988 - Papers sent to publisher and journal for publication

9.6. Conference Program Sessions

I. Opening Session: Chairman, Walter Heck, USDA-ARS/N. C. State University, Raleigh, NC, USA
Co-Chairman, Richard Adams, Oregon State University, Corvallis, OR, USA

1. Introduction

2. Key note speaker - will address in a general way the need for crop loss assessment activities (Speaker - EPA Official)

3. Conference overview papers (invited speakers) - These papers will develop the basic framework for sessions II-VII. The intent of

these papers is to develop the broad overview of what is required to accomplish a crop loss assessment and the approach taken by NCLAN. This should include meteorology/atmospheric chemistry/monitoring aspects, basic field approaches to yield assessments, and economic approaches.

a) The Major Needs for A Crop Assessment Program - (Speaker: Donald A. Holt, University of Illinois, Urbana, IL, USA)

This presentation will highlight the need to understand the air pollution system and focus on the need for good environmental monitoring. The paper will develop the need for pollutant dose-crop yield responses developed to predict effects at different pollutant concentrations or doses. Finally the paper will highlight the need to incorporate the above concepts into an economic analysis.

b) Research Approaches to Pollutant Crop Loss Functions - (Speaker: Douglas P. Ormrod, University of Guelph, Guelph, Ontario, Canada)

This presentation will discuss a variety of approaches to the development of crop loss functions involving air pollutants. The primary approaches utilize field chambers, open field systems, or a statistical/epidemiology method to assess losses. Potential strengths and weaknesses of the different approaches will be highlighted; modeling concepts will be included.

c) The NCLAN Program for Crop Loss Assessment - (Speaker: Eric M. Preston, U.S. EPA-CERL, Corvallis, OR, USA)

This presentation will develop the background for NCLAN; develop rationale for the approach taken in NCLAN; highlight accomplishments; define issues that NCLAN wanted to address but didn't; develop issues that should be addressed in future research.

Note: Invited speakers in Sessions II-VII should briefly address historical aspects of their topic, highlight recent accomplishments (using a synthesis approach) and address directions that this research should take to be most productive.

II. Meteorology/Atmospheric Chem./Regional Monitoring - Extrapolation:
Chairman, Bruce Hicks, NOAA/ATDD Environmental Research Lab, Oak Ridge, TN, USA
Co-chairman, Allen S. Lefohn, A.S.L. & Associates, Helena, MT, USA

1. Meteorology - Atmospheric Chemistry & Long-Range Transport (Speaker: Paul Altshuller, U.S. EPA, Research Triangle Park, NC, USA)

This presentation will set the stage for the descriptions of environmental quality to which crops are exposed. It should focus on oxidant (ozone-O_3) air pollutants; describe atmospheric reactions responsible for O_3 production; describe atmospheric conditions that will promote long-range transport of ozone and/or primary pollutants involved in photochemical reactions; and describe the decay process involved in removing the different pollutants from the atmosphere. Where it is pertinent to understand dynamic changes in composition of the pollutant complex, the presentation should also present the role of pollutants other than O_3 in atmospheric reactions. Emphasis should be placed on explaining the formation of phytotoxicants, expected decay rates, and the meteorological factors associated with long-range transport.

2. Regional Monitoring - Extrapolation (Speaker: Peter Knudsen, Montana College of Mineral Science and Technology, Butte, MT, USA)

   The intent of this presentation is to characterize the pollutant exposure potential throughout the nation with particular attention to cropped regions. For economic and practical reasons large areas of agricultural land will probably never be adequately monitored for air pollutants. Consequently some technique (such as kriging) must be employed to extrapolate monitoring data into these areas for a reasonable assessment of air quality. The presentation will identify methods of data extrapolation that may have a potential for describing conditions in inadequately monitored areas and give the strengths and weaknesses of these methods. Primary emphasis will be given to O_3; discussion of problems with SO_2 and NO_x will be addressed.

3. Dose Statistics for Use in Crop Assessments (Speaker: William Hogsett, U.S. EPA-CERL, Corvallis, OR, USA)

   Pollutant exposure has been expressed in various ways depending upon the intended use of the data and preferences of individuals compiling the monitoring data. Methods of averaging and lengths of averaging time have varied considerably when researchers describe exposures in their studies. The presentation will discuss strengths and weaknesses of some of the different dose statistics used and indicate possible avenues through which a description of the effective exposure dose may be more clearly defined. Primary emphasis will be given to O_3; discussions of approaches for SO_2 and NO_x will be included.

4. Short contributed papers pertinent to above (e.g. - natural background O_3, different dose statistics, methods of extrapolation).

5. Contributed posters pertinent to above are encouraged.

III. Yield Assessment Using Field Approaches for Measuring Crop Losses:

Chairman, Michael Unsworth, Institute of Terrestrial Ecology,
Midlothian, Scotland
Co-Chairman, Howard E. Heggestad, Silver Springs, MD, USA

1. The Use of Field Chambers for Yield Assessment (Speaker: Allen S. Heagle, USDA-ARS/NCSU, Raleigh, NC, USA; co-authors Robert J. Kohut, Lance W. Kress, Patrick Temple)

The presentation will describe the field chambers used and identify both weaknesses and strengths. The purpose of field chambers is to grow experimental crops under "normal" cultural conditions while the pollutant dosage is being controlled. Field chambers have recognizable deficiencies which are difficult or expensive to correct. These deficiencies should be identified and alternatives suggested. The primary focus should be on results and future research directions. The presentation may be designed to treat the results on a crop-by-crop basis and identify discrepancies in results. It will discuss several studies and provide the best possible explanation for variations shown in successive years of study or between study sites.

2. The Use of Open Field Systems for Yield Assessment (Speaker: Andy McLeod, Central Electricity Research Lab, Leatherhead, Surrey, United Kingdom)

Known or suspected undesirable chamber effects have prompted the consideration of experimental techniques without chambers. Examples of such techniques include the use of chemical additives to protect against pollutant injury, extensive field surveys, comparison of crop response to historical responses, application of and protection against pollutant exposure by dilution tubes within the field, and the use of open field exposures. This presentation should focus on experiments in which mechanisms were installed in open fields to provide a concentration gradient across a population of plants or in some other way provide a series of pollutant exposure dilutions without enclosing the plants. From the review of the different procedures, an evaluation should be made of the effectiveness of the system(s) on different types of crops. The primary focus should be on results and future research directions.

3. The Use of Statistical/Epidemiological Approaches to Yield Assessment (Speaker: John A. Laurence, Boyce Thompson Institute, Ithaca, NY, USA)

Plant pathologists and entomologists have used controlled field sampling and statistical/modeling procedures to assess regional crop losses from pest infestation. The use of these and similar procedures for assessment of crop loss from pollutants will be developed. The presentation should describe the techniques as they can be or have been adapted for use in air pollution studies. Primary emphasis should be on results and future research directions.

4. Short contributed papers pertinent to above (e.g. - experiment results, use of protectants, results using other field systems).

5. Contributed posters pertinent to above are encouraged.

IV. The Value of Physiological Understanding in Crop Loss Assessment: Chairman, David T. Tingey, U.S. EPA-CERL, Corvallis, OR, USA
Co-chairman, Robert Amundson, Boyce Thompson Institute, Ithaca, NY, USA

1. Deposition/Pollutant Uptake (Speaker: George Taylor, Jr., Oak Ridge National Lab, Oak Ridge, TN, USA)

The focus should be on deposition/uptake of gaseous pollutants such as O_3 but characteristics of deposition of solid and liquid pollutants should be discussed. Deposition within chambers should be compared with deposition in the open field. The presentation should evaluate the effects of climatic conditions such as wind velocity, resistance, and direction on deposition and uptake. Effects of temperature, light and moisture on systems that control transfer from the atmosphere to internal leaf tissue should be discussed in detail. The use of this information in crop loss assessment should be addressed.

2. Mechanisms of Pollutant Stress (Speaker: Robert L. Heath, University of California, Riverside, CA, USA)

The various expressions of stress induced by air pollutants should be described and the mechanisms involved in inducing the stress should be identified. The presentation should make comparisons of stress induced by unfavorable environment, nutrient imbalance and other such factors with stress induced by air pollutants. In some instances the stress may be due to erosion of cuticle or by stimulation of the guard cells but in most instances it is probably induced by chemical and structural changes in internal leaf tissue. The physiological and biochemical changes should be discussed in some detail.

3. Growth and Carbon Allocation Associated with Pollutant Stress (Speaker: Joseph E. Miller, USDA-ARS/North Carolina State University, Raleigh, NC, USA)

This paper will focus on growth analyses from field experiments and research associated with carbon allocation in plants under stress. The relative growth effects on forage systems of two or more species will be included.

4. Short contributed papers pertinent to above (e.g. - experimental results, membrane studies, gas exchange studies, carbon allocation, use of tracers).

5. Contributed posters pertinent to above are encouraged.

V. Interactive Stress Factors, Abiotic and Biotic: Chairman, Leonard Weinstein, Boyce Thompson Institute, Ithaca, NY, USA; Co-chairman, Richard A. Reinert, USDA-ARS/N.C. State University, Raleigh, NC, USA

1. Importance of Pollutant Mixtures for Crop Loss Assessment (Speaker: T. A. Mansfield, University of Lancaster, Lancaster La1 4YQ, United Kingdom)

   Normally the polluted atmosphere is a complex mixture of gases, liquids and solids. Interactions of these materials in the air, on the plant surface or within the tissues may significantly alter plant reaction. It may not be possible in the short time available to discuss all known and potential interacting mechanisms but interactions between all major air pollutants should receive appropriate attention. A primary thrust should be on how mixtures can affect crop loss assessment and needed research.

2. Abiotic Factors Affecting Crop Loss Assessment (Speaker: Donald Krizek, USDA-ARS, Beltsville, MD, USA)

   The presentation will provide evidence of the influence of abiotic factors on response of crop plants to elevated pollutant concentrations. The paper will focus on soil moisture stress but will include other edaphic and climatic factors. The primary focus will be on results that highlight our current level of understanding and research that should be accomplished.

3. Biotic Factors Affecting Crop Loss Assessment (Speaker: William J. Manning, University of Massachusetts, Amherst, MA, USA)

   This presentation will provide evidence of the influence of biotic factors on the response of crop plants to elevated pollutant concentrations. The paper will cover results using insects and plant disease organisms. The primary focus will be on results that highlight our current level of understanding; research needs will be addressed.

4. Short contributed papers pertinent to above (e.g. - experimental results on pollutant mixtures, abiotic or biotic stress interactions with pollutants such as O_3, SO_2 or NO_2).

5. Contributed posters pertinent to above are encouraged.

VI. Statistical and Simulated Modeling Approaches: Chairman, V. C. Runeckles, University of British Columbia, Vancouver, Canada
Co-Chairman, Eric M. Preston, U. S. EPA, Corvallis, OR, USA

1. Statistical Approaches to Assessing Crop Losses (Speaker: John Rawlings, N. C. State University, Raleigh, NC, USA)

   This presentation will explain why particular statistical approaches were selected for the NCLAN program and make comparisons with other methods that might be considered, giving strengths and weaknesses of each method.

2. Process Level Models and Their Use in Crop Loss Assessment (Speaker: R. J. Luxmoore, Oak Ridge National Lab, Oak Ridge, TN, USA)

   The presentation will discuss advantages and disadvantages of using process-level models in a program such as NCLAN; show how these models can address assessment questions on a site basis; and, discuss how these might add to the value of regional/national crop loss assessment efforts.

3. Regional/National Crop Loss Assessment Modeling Approaches (Speaker: Sharon K. LeDuc, USDC/NOAA, Columbia, MO, USA)

   The presentation will show how the statistical and process level models can be used to support assessment efforts; and, present a reasonable modeling approach for the regional/national assessment of crop losses.

4. Short contributed papers pertinent to above (e.g. - different statistical and simulated modeling approaches, model results).

5. Contributed posters pertinent to above are encouraged.

VII. Economic Considerations and Policy Implications (Criteria and Standards): Chairman, O.C. Taylor, University of California, Riverside, CA, USA
Co-Chairman, Patricia Irving, NAPAP, Washington, DC, USA

The three invited papers are considered the culmination of the assessment effort; two dealing with economic aspects and the third with risk management at the policy level and how the assessment effort would be used in policy decisions.

1. The Role of Economics in Decision Making (Speaker: Ralph C. d'Arge, University of Wyoming, Laramie, WY, USA)

   The paper is to present and briefly discuss the fundamentals of benefit-cost analysis related to environmental/resource questions or policies. Focus would be on general economic valuation questions, including how economic values or measures change in social welfare across diverse effects and groups. This overview paper would provide a lead-in to the second paper.

2. Specific Economic Approaches, Results and Implications Arising from the NCLAN Program (Speaker: Richard Adams, Oregon State University, Corvallis OR, USA)

   The paper will be a detailed discussion of the use of cost-benefit analysis in the NCLAN program and presentation of the economic results from the program.

3. Policy Implications from Crop Loss Assessment Research - the U.S. Perspective (Speaker: Bruce Jordan, U. S. EPA, Research Triangle Park, NC, USA)

   The paper should discuss how economic information and other information contribute to informed policy making. This paper will thus define the reality of policy making in the context of vegetative effects of ozone.

4. Short contributed papers pertinent to above (e.g. - different economic approaches and results).

5. Contributed posters pertinent to above are encouraged.

SECTION 10

NCLAN PUBLICATION STATUS

This listing updates Section 9 in the 1984 Annual Report (21).

10.1. Published

This section summarizes NCLAN publication status from September 1985 (if revised) through May 1987. Keywords are shown in ( ) at the end of most citations. We have divided this section into: abstracts, inhouse and other reports, published proceedings, and journal articles.

10.1.1. Abstracts

1) Flagler, R.B., M.H. Unsworth, A.S. Heagle, and V.M. Lesser. 1983. Alteration of growth of soybeans in response to ozone. Agronomy Abstracts. p. 90.

2) Flagler, R.B., R.P. Patterson, and A.S. Heagle. 1984. Ozone and water deficit effects on soybean yield and physiology. Agronomy Abstracts. p. 104.

3) Flagler, R.B., A.S. Heagle, and W.W. Heck. 1985. Ozone and water deficit effects on soybean. Paper 85-2p.11. Presented at Air Pollution Control Association Meeting, June 16-21, 1985. Detroit, MI.

10.1.2. Inhouse and Other Reports

1) Heck, W.W., O.C. Taylor, Richard M. Adams, Gail Bingham, Joseph E. Miller, Eric M. Preston, and Leonard H. Weinstein: R.G. Amundson, R.J. Kohut, J.A. Laurence, W.W. Cure, A.S. Heagle, T.J. Tish, H.E. Heggestad, L.W. Kress, G.E. Neely, J.O. Rawlings, and P. Temple. 1985. National Crop Loss Assessment Network (NCLAN), 1984 Annual Report. EPA-600/3-86-041, Corvallis Environ. Res. Lab., Office of Res. and Develop., U.S. EPA, Corvallis, OR. July 1985, 228 p.

2) Kress, L.W., A.-C. McGraw, P.M. Irving, H.J. Smith, and W. Prepejchal. 1986. National Crop Loss Assessment Network. In: Environmental Research Division Technicial Progress Report, Argonne National Laboratory, Argonne, IL. ANL-86-15, Jan. 84-Dec. 1985. Section 3.3: pp. 3-29-3-36.

3) Heagle, A.S., W.W. Cure, and J.O. Rawlings. 1985. Response of turnips to chronic doses of ozone in open-top field chambers. Environ. Pollut. (Series A) 38:305-319.

4) Ziminski, P.K. and S.R. Holman. 1987. An automated data acquisition and control system for air pollution research. HP Chronicle (In Press).

10.1.3. Published Proceedings

1. Heck, W.W. 1987. Assessment of Crop Loss from Atmospheric Deposition in the U.S. A summary presented at the 41st Annual Convention of the Nat. ASsoc. of Conservation Districts, February 1-5, 1987, Reno, NV. 5 pp.

2. Guderian, R., D.T. Tingey and R. Rabe. 1985. Effects of photochemical oxidants on plants. pp. 127-333. In: "Air Pollution by Photochemical Oxidants: Formation, Transport, Control and Effects on Plants." (R. Guderian, ed.). Springer-Verlag, Ecological Studies 52, Berlin, West Germany.

3. Heck, W.W. and A.S. Heagle. 1985. SO_2 Effects on agricultural systems: A regional outlook. pp. 418-430. In: "Sulfur Dioxide and Vegetation: Physiology, Ecology and Policy Issues." (W.E. Winner, H.A. Mooney and R. Goldstein, eds.). Stanford University Press, Palo Alto, CA.

4. Heck, W.W. and A.S. Heagle. 1986. Assessment of Crop Loss from Atmospheric Deposition: A Case Study. In: "Atmospheric Deposition and Forest Productivity." Proc. of the 4th Regional Technical Conference at the 65th Annual Meeting of the Appalachian Society of American Foresters. Jan. 29-31, 1986. pp. 9-21. Raleigh, NC. Society of American Foresters, Blackburg, VA. SAF 86-06.

5. Kohut, R.J. 1986. The National Crop Loss Assessment Network (NCLAN): An update of research results and a program review. pp. 132-143. In: "Evaluation of the Scientific Basis for Ozone/Oxidant Standards." (S.D. Lee, ed.), Air Pollution Control Association, Pittsburgh, PA. (O_3, Crops)

6. McCarl, B.A., D. Brown, R.M. Adams, and J. Pheasant. 1986. Linking farm and sector models in spatial equilibrium analysis: An application to ozone standards as they affect corn belt agriculture. In: "Quantitative Methods for Market Oriented Economic Analysis over Space and Time." (T. Takayama and N. Uri, eds.). JAI Press, Greenwich, Conn. (In Press) (O_3, Corn, Modeling)

7. Tingey, D.T. 1985. The impact of ozone on vegetation. pp. 1-25. In: "Perspectives in Environmental Botany." (D.N. Rao, K.J. Ahmad, M. Yunus and S.N. Singh, eds.). Volume 1, Print House, Luchnow, India. Vol. 1:1-25.

8. Tingey, D.T. and D.M. Olszyk. 1985. Intraspecies variability in metabolic responses to SO_2. pp. 178-205. In: "Sulfur Dioxide and Vegetation: Physiology, Ecology, and Policy Issues." (W. Winner, H.A. Mooney and R. Goldstein, eds.). Stanford Univ. Press, Stanford, CA.

10.1.4. Journal Articles

1) Adams, R.M. 1986. Agriculture, forestry, and related benefits of air pollution control: A review and some observations. Amer. J. Agric. Econ. 68:464-472.

2) Adams, R.M., J.M. Callaway, and B.A. McCarl. 1986. Pollution, agriculture, and social welfare - The case of acid deposition. Can. J. Agric. Econ. 34:3-20.

3) Adams, R.M., S.A. Hamilton, and B.A. McCarl. 1986. The benefits of air pollution control: The case of ozone and U.S. agriculture. Amer. J. Agric. Econ. 68:886-893. (O_3, Economics, Yield)

4) Amundson, R.G., R.J. Kohut, A.W. Schoettle, R.M. Raba, and P.B. Reich. 1987. Correlative reductions in whole-plant photosynthesis and yield of winter wheat caused by ozone. Phytopathology 77:75-79.

5) Cure, W.W., J.S. Sanders, and A.S. Heagle. 1986. Crop yield response predicted with different characterizations of the same ozone treatments. J. Environ. Qual. 15:251-254. (O_3, Yield, Crops, Exposures)

6) Flagler, R.B., R.P. Patterson, A.S. Heagle and W.W. Heck. 1987. Ozone and soil moisture deficit effects on nitrogen metabolism of soybean. Crop Science. (In Press).

7) Garcia, P., B.L. Dixon, J. Mjelde, and R.M. Adams. 1986. Measuring the benefits of environmental change using a duality approach: The case of ozone and Illinois cash grain farms. J. Environ. Econ. and Manag. 13:69-80. (O_3, Economics, Modeling, Crops)

8) Harper, S.L., D.T. Tingey and W.E. Hogsett. 1985. Automation of experiments with a hand-held programmable calculator. American Laobratory 17:134-142.

9) Heagle, A.S., W.W. Heck, V.M. Lesser, and J.O. Rawlings. 1987. Effects of daily ozone exposure duration and concentration fluctuation on yield of tobacco exposed to chronic doses of ozone. Phytopathology 77:(In Press).

10) Heagle, A.S., W.W. Heck, V.M. Lesser, J.O. Rawlings and F. Mowry. 1986. Injury and yield response of cotton to chronic doses of ozone and sulfur dioxide in open-top chambers. J. Environ. Qual. 15:375-381. (Cotton, Yield, Injury)

11) Heggestad, H.E., J.H. Bennett, E.H. Lee, and L.W. Douglass. 1986. Effects of increasing doses of sulfur dioxide and ambient ozone on tomatoes: plant growth, leaf injury, elemental composition, fruit yields and quality. Phytopathology 76:1338-1344.

12) King, D.A. 1987. A model for predicting the influence of moisture stress on crop losses caused by ozone. Ecol. Modelling 35:29-44. (O_3, Soybean, Modeling, Moisture Stress)

13) King, D.A. and W.L. Nelson. 1987. Assessing the impacts of soil moisture stress on regional soybean yield and its sensitivity to ozone. (In Press) (O_3, Modeling, Soybean, Moisture Stress)

14) Kohut, R.J., R.G. Amundson, and John A. Laurence. 1986. Evaluation of growth and yield of soybean exposed to ozone in the field. Environ. Pollut. 41:219-234. (O_3, Soybean, Yield, Growth)

15) Kohut, R.J, R.G. Amundson, J.A. Lawrence, L. Colavito, P.L. van Leuken, and P. King. 1987. Effects of ozone and sulfur dioxide on the yield of winter wheat. Phytopathology 77:71-74.

16) Lefohn, A.S. and D.T. Tingey. 1985. Injury response of *Phaseolus vulgaris* to ozone flux density. Atmospheric Environment 19:206-207.

17) Lefohn, A.S., W.E. Hogsett and D.T. Tingey. 1987. The development of sulfur dioxide and ozone exposure profiles that mimic ambient conditions in the rural southeastern United States. Atmospheric Environment 21:659-670.

18) Lefohn, A.S., H.P. Knudsen, J. Logan, J. Simpson and C. Bhumralkar. 1987. An evaluation of the kriging method, as applied by NCLAN, to predict 7-h seasonal ozone concentrations. J. Air Pollut. Cont. Assoc. 37:595-602.

19) McCarl, B.A., S.A. Hamilton, and R.M. Adams. 1985. Improving the performance of programming-based environmental analyses of agriculture. Amer. J. Agric. Econ. 67:407-413. (O_3, Economics, Modeling, Crops)

20) Olszyk, D.M. and D.T. Tingey. 1985. Interspecific variation in SO_2 flux. Leaf surface versus internal flux and components of leaf conductance. Plant Physiology 79:949-956.

21) Olszyk, D.M. and D.T. Tingey. 1985. Metabolic basis for injury to plants from combinations of O_3 and SO_2: Studies with modifiers of pollutant toxicity. Plant Physiology 77:935-939.

22) Olszyk, D.M. and D.T. Tingey. 1986. Joint action of O_3 and SO_2 in modifying plant gas exchange. Plant Physiology 82:401-405.

23) Rodecap, K.D. and D.T. Tingey. 1986. Ozone-induced ethylene release from leaf surfaces. Plant Science 44:73-76.

24) Snow, M.D. and D.T. Tingey. 1985. Evaluation of a system for the imposition of plant water stress. Plant Physiology 77:602-607.

25) Taylor, G.E., Jr., D.T. Tingey and C.A. Gunderson. 1986. Photosynthesis, carbon allocation, and growth of sulfur dioxide ecotypes of Geranium carolinianum L. Oecologia 68:350-357.

26) Temple, P.J. 1986. Stomatal conductance and transpirational responses of field-grown cotton to ozone. Plant, Cell, and Environ. 9:315-322. (O_3, Cotton, Soil Moisture Stress)

27) Tingey, D.T., K.D. Rodecap, E.H. Lee, T.J. Moser and W.E. Hogsett. 1986. Ozone alters the concentrations of nutrients in bean tissue. Angewandte Botanik 60:481-493.

28) Tingey, D.T. and W.E. Hogsett. 1985. Water stress reduces ozone injury via a stomatal mechanism. Plant Physiology 77:944-947.

10.2. Submitted

1) Flagler, R.B., A.S. Heagle, R.P. Patterson and W.W. Heck. 1987. Growth of soybeans as affected by ozone and soil moisture content. Crop Science. (Submitted).

2) Gish, T.J., E.H. Heggestad, J.H. Bennett, and L.W. Douglas. 1987. Effects of ozone, sulfur dioxide and soil moisture stress on soybean yields. Agron. J. (Submitted) (O_3, SO_2, Soybean, Yield, Drought)

3) Heagle, A.S., R.B. Flagler, R.P. Patterson, V.M. Lesser, S.R. Shafer and W.W. Heck. 1987. Effect of soil moisture deficit on injury and yield response of soybean to chronic doses of ozone. Crop Science. (Submitted).

4) Irving, P.M., L.W. Kress, L.G. Hanshaw and D. Eaton. Impact of O_3 and SO_2 on four field corn hybrids. II. Physiology and biochemistry. Phytopathology (Submitted).

5) King, D.A., A.S. Heagle and R.B. Flagler. 1987. Evaluation of an ozone x moisture stress interaction model for soybean. Ecological Modelling (Submitted).

6) Kohut, R. Evaluation of the accuracy of time-sharing monitoring in determining short- and long-term average concentrations of ozone. Atmospheric Environment (Submitted).

7) Kress, L.W., J.E. Miller, and H.J. Smith. 1987. Impact of ozone on yield of four soybean cultivars. (Rewriting) (O_3, Soybean, Yield, Cultivars)

8) Kress, L.W., P.M. Irving, W. Prepejchal and H.J. Smith. Impact of O_3 and SO_2 on four field corn hybrids. I. Growth and yield. Phytopathology (Submitted).

9) Lefohn, A.S., C.E. Davis, C.K. Jones, D.T. Tingey and W.E. Hogsett. Co-occurrence patterns of gaseous air pollutant pairs at different minimum concentrations in the United States (Submitted).

10) Lefohn, A.S., R.J. Kohut and J.A. Laurence. A comparison of indices that describe the relationship between ozone exposure and agricultural crop yield reduction (Submitted).

11) Temple, P.J. and L.F. Benoit. Effects of ozone and water stress on canopy temperature, water use and water use efficiency of alfalfa. Agronomy Journal (Submitted).

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